AL-TR-1992-0014

AD-A262 417

ARMSTRONG LABORATORY

HYBRID OXYGEN SYSTEM

W. David Lee

Arthur D. Little, Incorporated
Acorn Park
Cambridge, MA 02140-2390

CREW SYSTEMS DIRECTORATE
Brooks Air Force Base, TX 78235-5000

October 1992

Final Technical Report for Period September 1986 - December 1991

Approved for public release; distribution is unlimited.

AIR FORCE MATERIEL COMMAND
BROOKS AIR FORCE BASE, TEXAS 78235-5000

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

George W. Miller

GEORGE W. MILLER, Major, USAF
Project Scientist

F. W. [signature]

F. WESLEY BAUMGARDNER, Ph.D.
Chief, Crew Systems Branch

[signature]

RICHARD L. MILLER, Ph.D.
Chief, Crew Technology Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 1992	Final September 1986 - December 1991

4. TITLE AND SUBTITLE
Hybrid Oxygen System

5. FUNDING NUMBERS
C - F33615-86-C-4505
PE - 62202F
PR - 7930
TA - 11
WU - 86

6. AUTHOR(S)
W. David Lee

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Arthur D. Little, Incorporated
Acorn Park
Cambridge, MA 02140-2390

8. PERFORMING ORGANIZATION REPORT NUMBER
56913-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
Crew Systems Directorate
Brooks Air Force Base, TX 78235-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL-TR-1992-0014

11. SUPPLEMENTARY NOTES
Armstrong Laboratory Technical Monitor: Maj. George W. Miller, (512)536-3361

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

Investigation of concepts for generating oxygen on-board combat aircraft and development of a bleed air-driven refrigeration, liquefaction, and cryogenic storage system for oxygen were undertaken in this study. A number of alternative approaches were examined while considering size, weight and power consumption. An open-loop bleed air-driven system was selected for design, development, and testing.

The bleed air-driven refrigeration unit achieved oxygen liquefaction temperatures of 90°K and liquefied and stored oxygen generated from a molecular sieve oxygen generating system (MSOGS). The oxygen was stored in cryogenic dewars, vaporized, and withdrawn from the system to simulate aircrew consumption. A heat exchanger flow reversing valving system was used to sublime and blow out condensates (water vapor and carbon dioxide) which normally collect in an open-loop refrigeration cycle operating from ambient air. The collection of condensate in the cryogenic system represented the largest technological area to overcome, and the reverse cycle system overcame the problem.

The laboratory demonstrator utilized a helium cycle cold head refrigeration unit in conjunction with a J-T valve to simulate a cryogenic expander to be used in the flight system. Further work to incorporate a cryogenic expander in place of the cold head and J-T valve is recommended.

14. SUBJECT TERMS
on-board oxygen generation and liquefaction
cryogenic storage of oxygen
bleed air-driven liquefaction system

15. NUMBER OF PAGES
226

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102

Table of Contents

List of Figures

List of Tables

Preface

This report was prepared under contract F33165-86-C-4505 to USAF Armstrong Laboratory. It represents the findings of a three-phase program to demonstrate the feasibility of a hybrid oxygen generation and storage system for combat aircraft. The first and second phases of the program centered on a study of alternative approaches to achieving the objective and the design of a laboratory demonstrator, respectively. Phase III was the culmination of the program in which a laboratory demonstrator was fabricated and tested.

The technical manager for USAF Armstrong Laboratory and point of contact was:

Major George W. Miller
Armstrong Laboratory (AL/CFTS)
Human Systems Division
Brooks Air Force Base, Texas 78235-5000
Tel. 512/536-3361

for Arthur D. Little, Inc.:

W. David Lee, Vice President and Managing Director
Technology and Product Development
20 Acorn Park
Cambridge, Massachusetts 02140-2390
Tel. 617/864-5770

HYBRID OXYGEN SYSTEM

1. Summary

This program was conducted to examine the feasibility of liquefying and storing oxygen generated by a molecular sieve oxygen generating system (MSOCS). The principles of the liquefaction system were proven in this laboratory-based development using commercially available cryogenic components.

Generation and storage of oxygen may be important in a variety of military operations. This study is focused on the generation and storage of oxygen on-board aircraft. Engine bleed air is the feed gas for the molecular sieve oxygen generation unit and the liquefaction unit. A compressed air based liquefaction system was selected for this application for the following reasons:

- utilization of aircraft engine bleed air (compressed air) directly to produce refrigeration is the most efficient method for developing the required liquefaction;
- compressed air is a safe and readily available working fluid for the desired refrigeration system; and
- compressed air refrigeration cycle is tolerant of system leaks unlike the standard hermetic closed cycle refrigeration systems and may be more reliable and require less maintenance.

A variety of refrigeration systems were considered (see section 3.3). It was concluded that the best aircraft system from the basis of size, weight, and power consumption would be a liquefier driven solely by bleed air from the engine. Several mission profiles were examined, and it was concluded that a 5-liter storage system for fighter aircraft and a 10-liter system for transports would be appropriate for the missions. A Laboratory Demonstrator, capable of storing up to 10 liters of oxygen, was designed and successfully tested.

The major design and development issue identified during the course of the work was the steady deriming or removal of condensible buildup from the bleed air in the cryogenic system with a technique that would not adversely impact the system operation. A reversing derime cycle is an elegant technique in which the heat exchanger process stream is reversed, thus venting the high pressure side where condensibles have collected to low pressure and gradually vaporizing these into the exhaust stream. This (deriming) approach does not interrupt the refrigeration cycle or the rate of production of the liquefier. A more radical approach considered was a hot gas defrost in which hot bleed air is brought directly to the cold end of the heat exchanger, and all condensibles are quickly vaporized. As will be discussed later, the deriming cycle worked exceedingly well, and the defrost approach was never attempted.

Once the fundamental cycle with periodic deriming of the bleed air refrigeration system was proven, the demonstration of liquefaction, storage, revaporization, and delivery of high purity oxygen was the next test objective. Two 5-liter capacity dewars were successfully filled to the desired level, and then gaseous oxygen was withdrawn simulating the crew demand.

Ninety percent oxygen was generated by the MSOGS unit; the oxygen was liquefied at about 90°K and stored in the dewars. During liquefaction, nitrogen was separated from the oxygen stream as demonstrated by the consistently lower concentration of oxygen in the gas vented from the filling dewars than the oxygen supplied. During the withdrawal of oxygen from the dewar the initial concentration was approximately 90% to 92%, and the concentration at the end of the withdrawal was 98% to 100%.

2. Introduction

This study is focused on integrating an MSOGS which will generate an inexhaustible supply of oxygen and an on-board liquefier into a self-contained system—the **Hybrid Oxygen System (HOS)**.

The logistic benefits of producing oxygen on-board aircraft and at remote locations with molecular sieve technology has generated considerable interest in the military. Currently, several aircraft are equipped with MSOGS.[1,2] The ability of MSOGS to produce oxygen in a safe, reliable fashion has created considerable interest. Further use of this oxygen generation technology could occur if a reliable and safe technique for storing large quantities of oxygen could be developed. Compression of oxygen for high pressure storage is hazardous and difficult to accomplish because standard compressor lubrication techniques are unacceptable with oxygen. Lubricants compatible with oxygen or nonlubricated compressors would need to be developed. Alternatively, gaseous oxygen generated by an MSOGS system can be liquefied by refrigeration at near-atmospheric pressure and stored.

A three-phase study was sponsored by the Armstrong Laboratory, AL/CFT, Crew Technology Division, Brooks Air Force Base (AFB), Texas, to demonstrate the feasibility of an HOS which would liquefy and store oxygen generated by an MSOGS. The scope of the work is summarized below.

Phase 1: The mission requirements and design trades for different types of HOS were examined. A variety of refrigeration approaches were investigated. Alternative refrigeration approaches are discussed in Section 3.3 (Chapter 3).

Phase 2: A Laboratory Demonstrator was designed with commercially available components to demonstrate the feasibility of the HOS. Also, a preliminary flight system was designed (Chapter 4).

Phase 3: The Laboratory Demonstrator was constructed and successfully tested (Chapter 5).

Computer simulations of the system components and laboratory test raw data, analyzed data, and graphics are contained on the Hybrid O_2 Master 3.5-inch diskette (available from AL/CFT) and are accessible with Lotus 1-2-3, Version 2 or later, or Quattro Pro, Version 2 or later.

1 Routzahn, Richard L., "An Oxygen Enriched Air System for the AV-8A Harrier," Report No. NADC-81198-60, Naval Air Development Center, Warminster, PA (1981).

2 Tedor, John B. and James Clink, "Manrating the B1-B Molecular Sieve Oxygen Generation System," Report No. USAFSAM-TR-87-4, USAF School of Aerospace Medicine, Brooks AFB, TX (1987).

3. Phase I: Feasibility Study

Essential questions of the method of liquefaction and storage of oxygen generated by the on-board MSOGS had to be answered. Phase I of the program was initiated to identify alternative system designs and choose the most promising. A systematic approach was adopted which started with the identification of the oxygen requirement and then selection of the liquefaction system and its design.

3.1 Oxygen Requirements and Missions

The oxygen requirement for crew and passengers is dictated by the type of aircraft and its missions. Two main classes of aircraft were chosen:

> Combat/fighter - Cabin pressure decreases with altitude requiring the use of oxygen masks to sustain about 195 mmHg of oxygen partial pressure to each individual.
>
> Transport and Bomber - Cabin pressure is maintained at 8,000 ft cabin altitude throughout this mission, oxygen masks are needed for therapeutic uses (aeromedical evacuation) and for emergency conditions.

The mission duration will determine the total oxygen requirement, and typical missions are shown in Table 1.

Table 1. Mission Profile in Minutes

Aircraft No. of Crew	Fighter 1 or 2	Transport 9	Bomber 6
Pre-engine time on O_2 Ground hold	15-30 15	- 30	15 15
Flight time	100	600	450
Ground hold	N/A	120	N/A
Return time	N/A	600	N/A

All aircraft have stored oxygen as either liquid oxygen (LOX) or high pressure bottles for use as the primary or secondary oxygen source.

Oxygen flow volume requirements are dictated by human oxygen consumption and ventilation rates. While the actual metabolic consumption of oxygen at modest levels of activity may be 1 to 2 LPM normal temperature and pressure (NTP), the volume of respired air required is substantially greater, probably 5 to 10 LPM. In simulated air combat, the O_2 uptake may reach an average of 5.3 LPM with peaks of 10 LPM (Table 2).

Table 2. Oxygen Breathing Requirements

Activity	Metabolic O_2 Uptake LPM (NTP)	Ventilation Rate LPM (NTP)	Breaths/ Minute[3]
Rest	1	6	12
Modest Activity	2	12	24
Combat and G's Average	5	32	64
Peak Activity (NATO)	10	50	
Instantaneous Peak Flow	N/A	150-200[4]	

Published oxygen flow rates for military aircraft are summarized in Table 3. The variability in the MIL-D-8683B accommodates increased activity. These flow rates are consistent with the time averaged values derived from known physiological O_2 uptake requirements.

Table 3. Breathing Specifications

Publication	Published Breathing Volume Requirements LPM (ATP)
MIL-D-8683B (Baseline & high activity)	13.3 - 28
B-1B MSOGS Specification	13.3 - 26.7 Max
F-16 (Rated LOX usage)	12.0
B-1B Backup Usage	12.4
NATO (STANAG 3865)	25[5] - 50

Oxygen concentration requirements are generally consistent with the concentrations of the CRU-73 oxygen regulator, though variability between publications can be found. Figure 1 shows the MIL-D-8683B oxygen requirements. Curve B of this figure is the design concentration at each cabin altitude.

3.1.1 Oxygen Backup for Combat Aircraft Crew The current MSOGS systems are generally supported by a 200 liter (NTP) per man high pressure backup. Ideally, a backup supply of at least 850[6] liters (NTP) per crew (MIL-D-8683B) for a 100-minute mission would be desired as shown in Table 4. To meet North Atlantic Treaty Organization (NATO) recommended levels of breathing, the backup requirement would probably be closer to 1,600 liters (NTP) per man. For a two-man crew, this amounts to a backup requirement of 3 to 4 liters of LOX.

3 Assuming .5 liters/breath.

4 NATO specification of 198 LPM ATPD for peak inspiration.

5 Minimum required at low bleed air pressure.

6 This value is derived for the 100-minute mission in Table A, Appendix 7.1, and provides 100% mission backup in the event of decompression and loss of MSOGS.

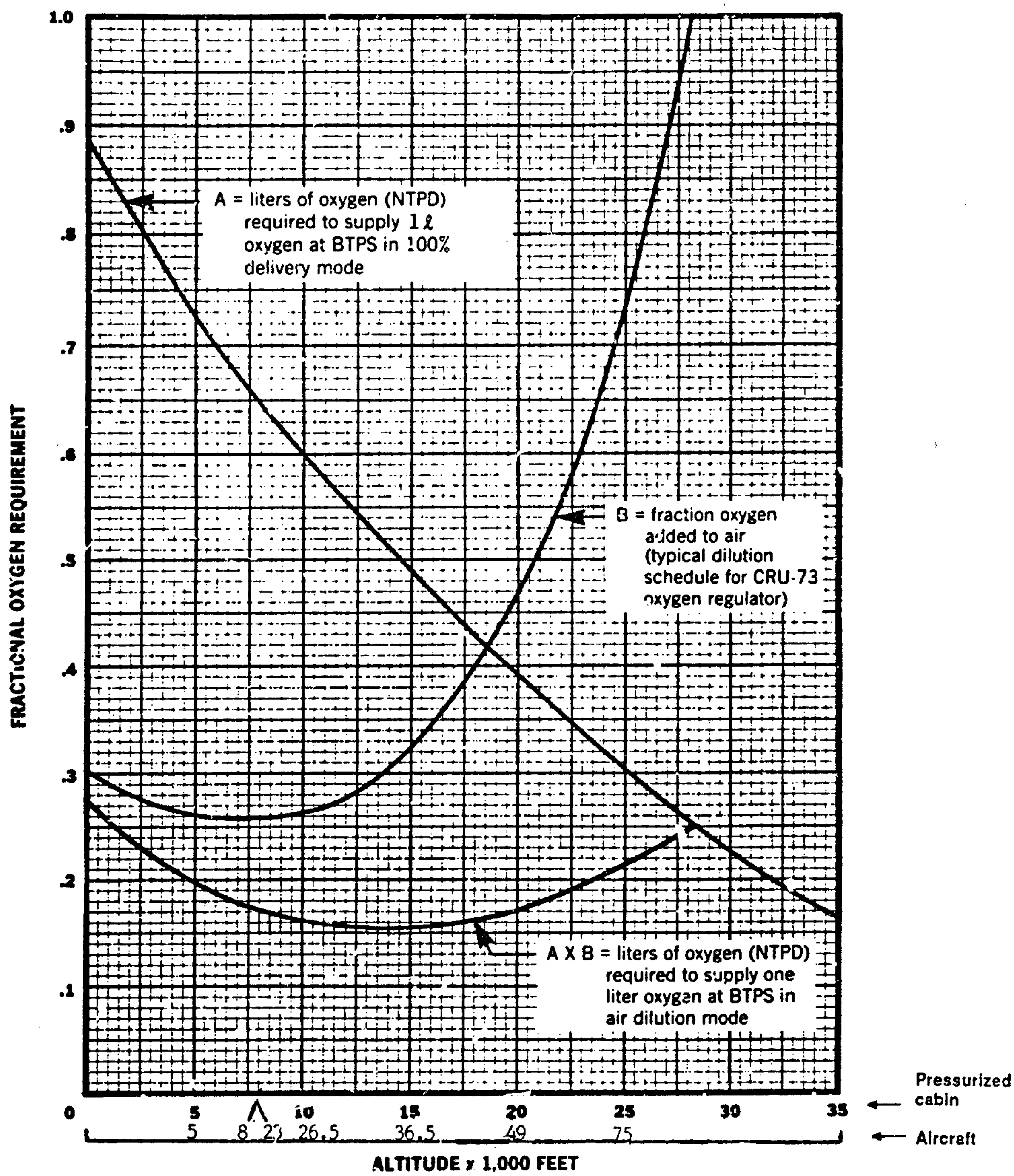


Figure 1. Fractional Oxygen Requirement vs. Cabin Altitude.

Table 4. Fighter (MSOGS) Backup Requirements

	O_2 Backup Liters @ NTP	Weight of High Pressure Bottle for Two Men
Practice	200 1/man	14 lbs
MIL-D-8683	850 1/man	26 lbs
NATO STANAG 3865	1,600 1/man	52 lbs

Backup for a transport crew amounts to 50% of the mission duration and is typically 25 liters of LOX (19,000 L NTP) which corresponds to more than 5 h of mission or more than one-half the total mission to comply with MIL-D-8683. The HOS will address this need.

Table 5 shows the typical stored supply of oxygen used with current MSOGS as compared to MIL-8683B requirements and to standard amounts carried as LOX. Higher back-up volumes are desirable to meet the total mission requirements for combat aircraft. An HOS could provide the backup oxygen through generation and storage of oxygen.

Table 5. Crew Stored Oxygen Available Liters/Man (NTP)

	Fighter	Bomber	Transport
Typical MSOGS Backup	200	550	Not established
MIL-8683B	850		
Standard LOX	2,200		2,100

<u>Passenger and Therapeutic Oxygen or Aeromedical Evacuation Requirements</u>

Stored oxygen requirements for transport aircraft are either:

- backup in case of cabin decompression or
- therapeutic (aeromedical evacuation).

The volume of passenger oxygen required is given as:

Passenger backup 2-75 liter LOX or 130,500 L-NTP
Therapeutic 15 liters LOX or 13,000 L-NTP

An HOS could be developed to provide part or all of the passenger or aeromedical evacuation requirements.

3.1.2 Demand Matching Another key function of the HOS would be to store oxygen to level the demand. A smaller MSOGS unit designed to meet the average (13 LPM/man) consumption rather than the peak (50 LPM/man) could be used.

The peak consumption rate creates a considerable problem at lower altitudes. An HOS storage system could draw on the stored liquid for peak demands and replenish the supply while at higher altitudes or lower O_2 consumption.

3.2 Benefits of the Hybrid Oxygen System

Logistic Autonomy

The HOS was conceived to achieve complete logistic autonomy for MSOGS while providing convenient LOX storage for reliability. Interviews with F-16 Special Project Office (SPO), AV8 SPO and others confirmed the perceived benefit of the stored LOX without the negative logistics. The HOS will eliminate routine servicing of the MSOGS backup oxygen system. Currently, the MSOGS backup oxygen system requires routine servicing due to usage and leakage. The HOS allows the crew to draw on the LOX at their own discretion without jeopardizing the backup volume necessary to meet the mission.

Engine OFF Supply of Breathing Gas

Pilots like to run breathing gas immediately upon entering the aircraft and prior to the operation of the engines. During this period, the MSOGS is not providing breathing gas and oxygen must be drawn from either a high pressure storage backup or LOX storage. The current oxygen demand of fighter aircraft is about 15 minutes of ground hold with the engine off. An HOS could meet this need with mission-to-mission storage of produced oxygen. With aircraft layovers of less than 3 to 5 days, the vaporization loss of the stored LOX will leave sufficient liquid oxygen to meet the preflight breathing needs.

Inflight Backup

The HOS will provide an inflight backup source of oxygen to allow the pilot to complete the mission should difficulties with the MSOGS occur.

Peak Shaving or Load Leveling

New NATO requirements indicate a need for 50 liters/min/man rating of MSOGS systems in order to meet peak combat crew oxygen breathing requirements while both MIL-D-19326F and MIL-D-8683B require an average of 13.3 liters/min. The HOS can be used to provide load leveling so that the MSOGS need only be sized for the mean load of 13.3 LPM ambient temperature and pressure (ATP). This leveling dramatically reduces its capacity requirement from 50 liters/min to approximately one-third that capacity.

To assess the possible benefit of the HOS, a fighter and bomber mission scenario was developed, and the system performance was simulated. Table 6 is a summary of the analysis, and additional tables (A-H) in Appendix 7.1 provide the analysis assumptions and the detailed data. The analysis includes the fighter and bomber on dilution, 95% oxygen at cabin altitude or 95% oxygen under decompression conditions. The simulation is contained on the Master disk under the file name HYBRIDOX.WK1.

Table 6. Summary Specifications Comparison for Backup and Peak Shaving Mission Scenarios

					System Size in Liters Storage, HX			System Weight in lbs	
Table			% Oxy at Start	Liquefier Capacity g/s	Std MSOGS	Hybrid System	Dewar	Std MSOGS	Hybrid
A	Fighter	Dilution air	75	.45	26	11	1.5	36	33
B	Fighter	95% oxygen	75	.9	54	20	3.2	84	47
C	Fighter	Decompression	75	.45	44	13	2.2	60	36
D	Fighter	Decompression	~0	.6	34	16	2.2	47	38
E	Bomber	Dilution air	75	.9	104	26	12	158	74
F	Bomber	95% oxygen	75	2.0	303	62	28	436	163
G	Bomber	Decompression	75	1.8	195	44	22	279	122
H	Bomber	Decompression	~0	1.8	144	49	22	211	86

Three cases for oxygen backup were examined: two missions in which dilution or 95% oxygen were consumed at cabin pressure; and another case in which cabin decompression and consumption at 13.3 LPM ATP are assumed. The decompression case represents the reasonable backup requirement and is the system design scenario.

The standard MSOGS includes the concentrator and the backup high pressure oxygen storage vessel. The HOS includes the concentrator, liquefier, and dewars for storage of the LOX.

Liquefier and Storage Dewar Size

The weight and volume benefit of the HOS designed to meet a cabin decompression is 40-50% weight reduction and 70-80% volume reduction over a standard MSOGS with high pressure bottle backup. For the fighter aircraft, two one-liter dewars integrated with a .5 g/sec liquefier provide sufficient backup and load leveling, while two ten-liter dewars are required for the bomber along with a 2 g/sec liquefier.

Aeromedical Evacuation

Considerable on-board oxygen is required for aeromedical evacuation transport aircraft for crew and passenger backup usage and as therapeutic oxygen. Crew and passenger backup usage is infrequent, and the current practice is to use one 25 and two 75 liter LOX dewars as backup. These dewars must be replenished on each flight due to boil-off (about 8 liters per day total). A small HOS could be used to maintain the stored LOX at desired levels, eliminating the regular logistic demand for LOX, depending on the interval between flights (the flights per week). Table 7 summarizes the size of the oxygen boil-off replenishment system as a function of the flights per week assuming the maximum boil-off of MIL-D-19326F. As the frequency of use increases, the dewars are replenished more often, and the size of the hybrid system is reduced. The system sizing assumptions for the aeromedical evacuation are the same as those used in Table 6 and are summarized in Appendix 7.1.

Table 7. Boil-Off Replenishment (12-hour missions)

Flights/Week	Liquefier LPM-NTP	Hybrid System Weight (lbs)
1	67	88
3	23	41
5	14	31
7	9	28

Retrofit

The HOS can supply oxygen pressures of 70 psi, hence, high pressure regulators can be used. Presently, MSOGS require special low pressure regulators.

High Purity

The HOS allows the MSOGS to run at high purity (about 95%) continuously, and peak oxygen demands are met by drawing on storage. The MSOGS concentration declines with flow rate above about 40 LPM normal temperature and pressure (NTP) at ground level. Oxygen can be liquefied for later higher demand, while the MSOGS is delivering high purity oxygen for current usage.

Electronics Cooling

Electronics cooling can be augmented by the use of this system. We estimate about 500 w of 40°F dry air will be available as excess cooling from the HOS.

Pilot Choices

The HOS allows the pilot to freely choose dilution or 95% oxygen during the mission because of the large stored volume of liquid oxygen. With a conventional MSOGS, capacity and concentration are linked to the performance of the MSOGS and the bleed air supply pressure. With the HOS, the stored oxygen allows the pilot to switch to 95% concentration while at high demand rates.

3.2.1 Technical Risks There are technical risks in the development phase as well as in the deployment phase of the HOS.

The major technological risk in the development phase is the performance and integration of the turboexpander envisioned for the bleed air liquefier. At the mass flow rates expected for the 40 LPM (NTP) liquefier, a very small high-speed turboexpander would be required. Expanders of this class are currently being developed by Creare, Inc., Hanover, NH, for cryogenic cooler applications in other military systems.

A miniature turboexpander concurrently was being developed by Creare during this project. Hence, we demonstrated HOS feasibility with standard components which simulate a turboexpander.

The second development risk is one of system failure due to contamination. Most cryogenic systems are closed cycle refrigerant systems in which the refrigeration fluid is a pure substance and continuously recycled inside of a hermetic unit. The bleed air-based liquefier is constantly processing ambient air, and along with it, considerable contaminants. Water vapor, carbon dioxide, and other condensibles will frost in the heat exchanger and ultimately deteriorate the

performance. This contamination process is inherent in the design, but can be used as a very important breathing gas purifier in a properly designed system. In this effort, management of the contaminants by the periodic deriming of the heat exchanger appeared successful.

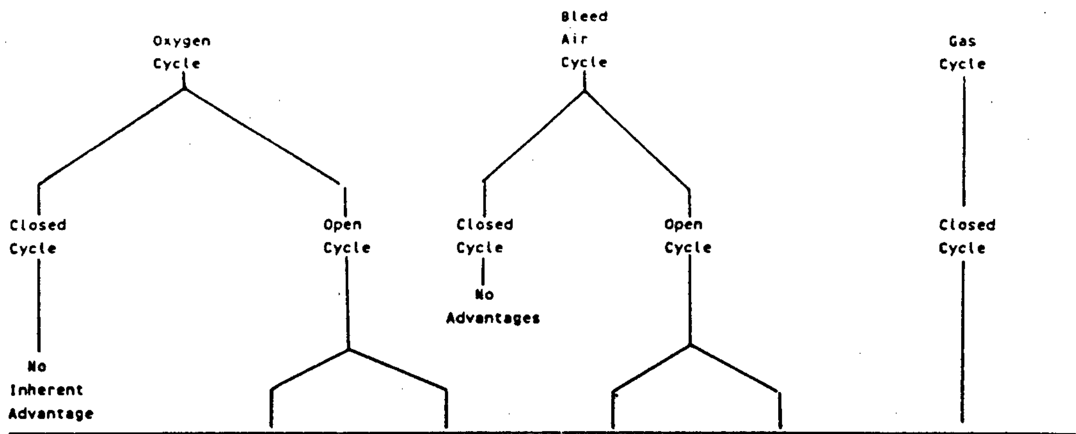
3.3 Hybrid System Refrigeration Trade Studies

The fighter aircraft application was chosen as more suitable for laboratory demonstration. This application requires a baseline module liquefier of 20-40 LPM-NTP (.45 to .9 g/sec). A number of refrigeration approaches were examined to provide the necessary liquefaction.

Figure 2 gives the summary comparison of alternative systems. There are six typical cryogenic refrigerator or liquefaction cycles that were considered.

- Reverse Brayton
- Reverse Rankine
- Stirling
- Gifford-McMahon
- Collins
- Closed Cycle Brayton

In general, the appropriateness of the cycle will be dictated by the availability or feasibility of components required. For instance, in column 2 the Rankine, Brayton, and Stirling cycle systems require a compressor which is probably infeasible for this project, since no oil-free, high pressure ratio oxygen rated compressor of a flight weight construction has been developed. Available oxygen compatible diaphragm compressors have limited life and are large mechanical systems probably weighing on the order of several hundred pounds for a relatively small flow volume. The Reverse Brayton cycle in an open cycle configuration is probably the approach most consistent with aircraft refrigeration. This cycle is used for environmental control on aircraft and offers the major advantage of small lightweight machinery. The Reverse Brayton cycle can take advantage of available bleed air for producing refrigeration, and, unlike the closed cycle units, will not degrade over time due to the gradual leakage loss of refrigerant which is generally encountered with closed cycle units, particularly helium-charged cryogenic refrigerators.



SYSTEM	1	2	3	4	5
TRADE FACTOR	10:1 Expander	10:1 Compressor and Expander	10:1 Compressor and Expander	5:1 Expander	Compressor and Expander
Typical Cycles	Brayton	Rankine Brayton Stirling	Rankine Brayton Stirling	Brayton	Gifford-McMahon (ADL) Stirling Collins Brayton (ADL)
Compressor	None	Oil Free	Any	None	Any
Weight $\frac{\text{lbs}}{\text{gr/sec of LOX}}$	200	Unacceptable		20	1,000 (G-M) 700 (Collins)
Volume $\frac{\text{liter}}{\text{gr/sec}}$	70			7	High
Cost (Relative)	Medium	Unknown	High	Medium	Low
Power Consumption $\frac{\text{watts}}{\text{gr/sec of LOX}}$	0	No lightweight oil-free compressor is readily available. A major development program would be required.	1,200[3]	0	2,300 (Collins) 10,000 (G-M)
Inlet Air Flow $\frac{\text{gr.air}}{\text{gr.LOX}}$	344 - ∞[1]	23	26[2]	35	22
Inlet Air Pressure	10:1		2:1	2:1	N/A
Reliability	Good	Unproven compressor	Unproven compressor	Unproven expander	3,000 hours (Collins) 8,000 hours (G-M) between overhaul
Minimum Altitude	20,000	0	0	0	0

[1] 213 J/g liquefaction and 6.1 J/g sensible cooling from O_2 cycle at 82°K with a 97% expander and 20% O_2. Otherwise, a two-phase expander would be required.

[2] 213 J/g liquid O_2 liquefaction and 59.7 J/g cooling air cycle (84°K) = 3.5 $\frac{\text{grams bleed}}{\text{gram/LOX}}$ with 75% expander plus 22 $\frac{\text{g/air}}{\text{g/LOX}}$ to produce the electric power.

[3] 125 J/g air compressor power x 6 g/gLOX.

Figure 2. Major Liquefaction Alternatives.

Compressor

Several of the systems (2 and 3) require a compressor. A cycle operating on the oxygen delivered from the concentrator and requiring additional compression will have substantial difficulties because it must be oil-free for safety reasons. Oil-free oxygen compressors capable of 10:1 compression ratios are highly specialized custom systems and not readily adaptable to lightweight operation. On the other hand, a compressor used in a bleed air system or a closed gas cycle can use any type of compressor including an oil-flooded unit because the hazard of explosion is eliminated. However, cleaning up of the entrained oil from the processed gas must be undertaken so that freeze out does not occur at the cold end. In many of the commercially available systems, the oil cleanup system is as large and as expensive as the compressor and expander combined. These deterrents require the addition of ancillary components, hence, making the compressor-free system alternatives (column 4) more attractive.

Newly available small high-speed turbocompressors can run oil free, but would require about five to eight stages of compression to raise the oxygen pressure from 5 ATM to 10 ATM, the pressure necessary to produce LOX directly. This type of system would certainly involve a major development.

Weight

Weight will depend on the cycle chosen and the need for a compressor and gas cleanup system. If the alternatives requiring a small turboexpander (columns 1 and 4) are used, the system weight is likely to be small relative to the other alternatives. An off-the-shelf closed cycle refrigerator using a standard oil-lubricated compressor and gas cleanup system may weigh as much as 1,000 lb/gram/second of LOX delivered. This result compares to the weight of an open cycle bleed air system of well under 30 lb/gram/second.

Volume

The relative volume of the alternative systems will be very similar to the relative weight of the systems. Turboexpanders will have extremely small rotors (1 inch diameter or less) for this application while the heat exchangers are likely to represent the largest component in the open cycle systems (1 and 4). A reciprocating expander has the advantage of much higher efficiency over a wider pressure ratio which means that less bleed air would be required for the open cycle systems than that shown in Figure 2. In addition, control start up and transient response of the expander will be more flexible than the very high speed turboexpanders which would be employed in such a small system. The reciprocating expander would, however, be heavier and bigger in volume than the turboexpander equivalent.

Cost

The ultimate cost of the system hardware will have two components: an initial development cost and a production cost. The values shown in Figure 2 are estimates of the relative cost of the different systems considering both development and production costs.

Power Consumption

The auxiliary electric power consumption for the different systems are dramatically different one from another. Systems 1 and 4 capitalize on the use of available bleed air pressure for the operation of the refrigerator or liquefier while Systems 2, 3, and 5 will require input power. The power requirements for a stand-alone refrigerator are quite high and, in conjunction with the weight penalty, make these Systems (2, 3, and 5) quite unattractive as compared to the open cycle Brayton systems.

Inlet Airflow Requirement

While Systems 1 and 4 do not require electric power consumption, they do require bleed air to operate the refrigerator or liquefier. While it is not intuitively obvious, there is a considerable difference between the two systems operating on the same bleed air pressure, System 1 employing oxygen after the concentrator and System 4 employing straight bleed air before the concentrator.

System 4 is essentially a nitrogen refrigerator and operates at refrigeration temperatures (79°K) below that of an oxygen-based working fluid for the same operating pressures. As a consequence, System 4 is about 17 times more efficient in the use of bleed air for producing LOX. In this system, the air would be used to produce a cold surface on which oxygen from the concentrator would be condensed.

System 1 operating on oxygen from the concentrator is likely to produce very little refrigeration for liquefying and storing oxygen at 1 ATM assuming realistic figures of 60%-70% expander efficiency (turboexpander at these pressure ratios). Systems 2, 3, and 5 use electric power, which can be derived from bleed air as well. We have assumed 54 w of electric power per 8 g/sec of 5 ATM bleed air.

Inlet Air Pressure

System 4 once again offers an advantage in that liquefaction can proceed at very modest inlet air pressures, though the amount of refrigeration would be proportional to the available pressure ratio, whereas System 1 must have an inlet pressure ratio of over 10:1 and then requires a nearly ideal expander to produce any refrigeration whatsoever.

The selection of the open cycle bleed air system (column 4), as the baseline system, was based on the forecasted weight and bleed air consumption. We believe that the system chosen is clearly more suitable for aircraft application because it will have the least impact on size.

Reverse Brayton Baseline System

Figure 3 shows the baseline system layout with the MSOGS conventional plumbing interfaced with the HOS.

Figure 4 shows the baseline system Temperature Entropy Diagram at the nominal design operating conditions. An inlet bleed air temperature of 300°K (70°F) or 533°K is assumed. The oxygen is cooled by heat exchange with the process stream and liquefied by the low pressure cold gas produced by the expander (point 3 of the cycle). The bleed air (process gas) is cooled by heat exchange to 120°K and then further cooled by the expander to about 84°K.

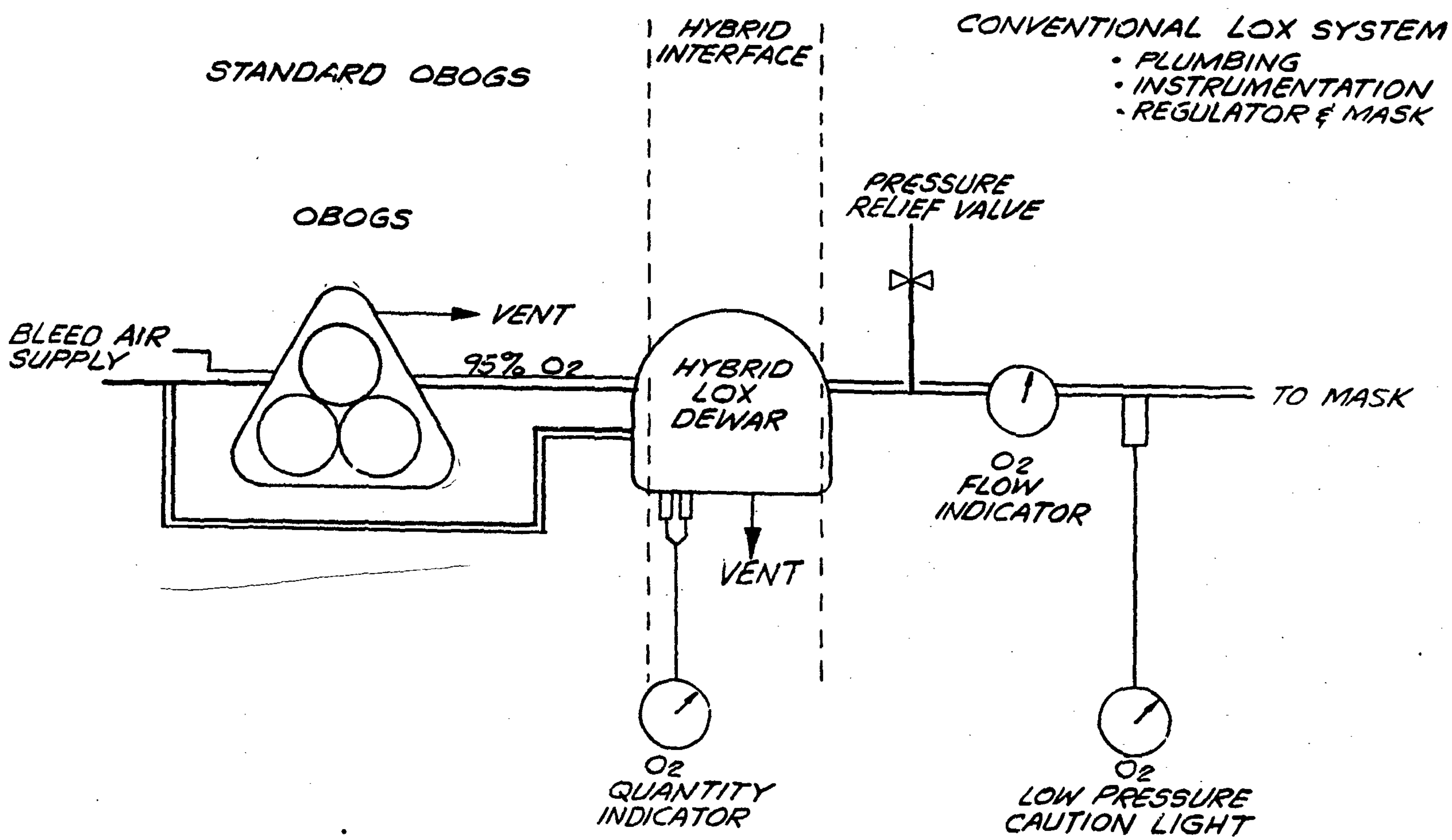


Figure 3. Hybrid Oxygen System - Baseline System Layout.

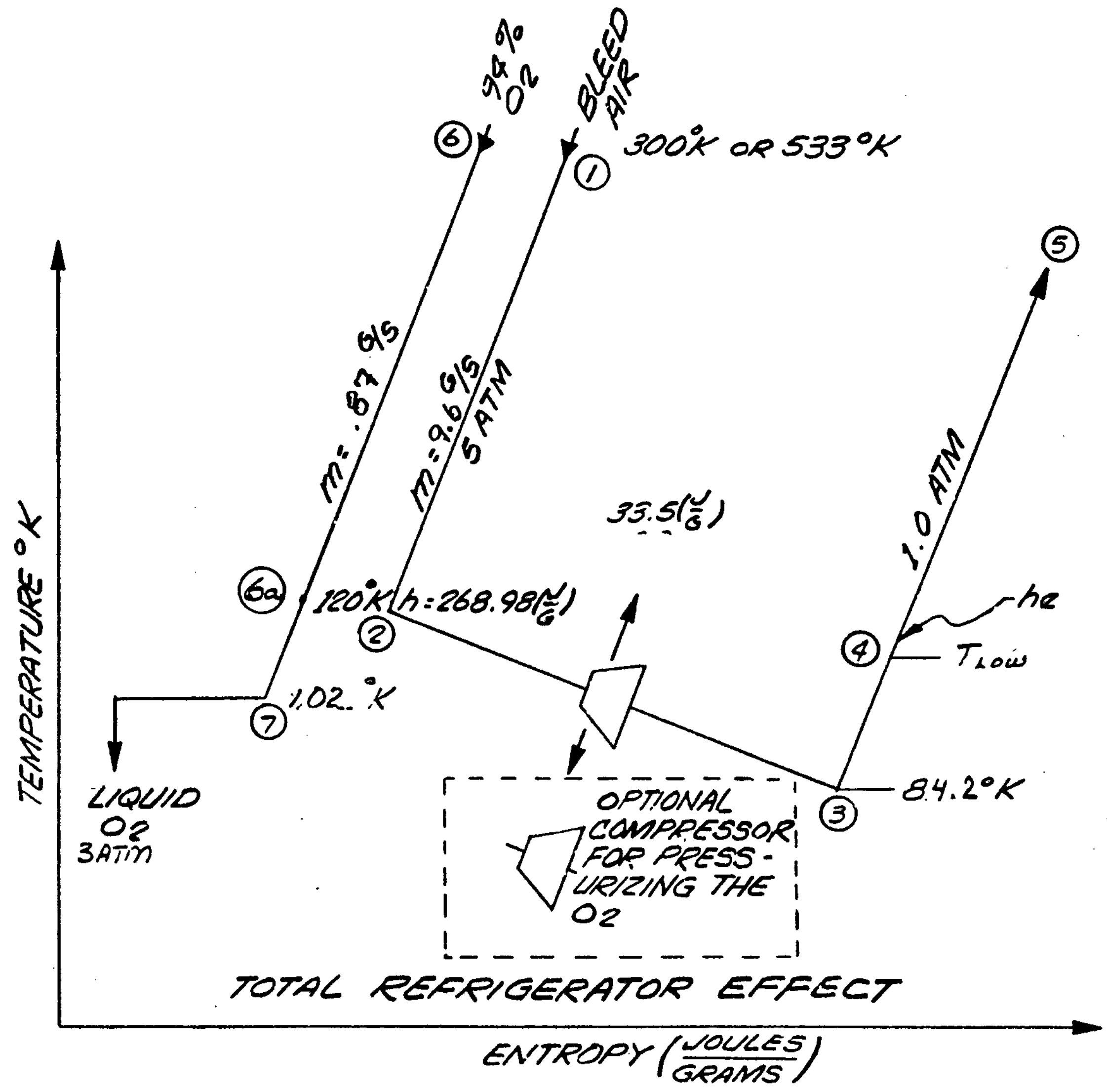


Figure 4. Bleed Air Refrigerator/Oxygen Liquefier System.

3.4 Aircraft Integration

As part of the study, Boeing Military Aircraft Company, Seattle, WA, was retained to evaluate the integration details for use of the HOS in a fighter aircraft. The summary of the report is reproduced here and the remainder of the report is given in Appendix 7.2.

1.0 Summary/Introduction

This report was prepared by the Boeing Advanced Systems Company to summarize the work conducted in support of Arthur D. Little, Inc. (ADL) on the HOS program. This report contains information on availability of bleed air for the HOS in typical fighter and bomber aircraft, discussions on system integration and feasibility, and identification of potential use and function of the additional cooling capability inherent in the HOS design.

The HOS discussed herein is based on the system shown in Figure 3. The HOS consists of an onboard oxygen liquefier which processes the concentrated oxygen from the onboard oxygen generation system (MSOGS) and stores it as liquid. Bleed air is required for oxygen generation and oxygen liquefaction.

Requirements for the MSOGS bleed air supply are based on oxygen breathing volume requirements. The design flow of oxygen from the MSOGS in the current HOS is set at 40 LPM (NTP). The required bleed air flow for liquefaction is a function of the MSOGS output, the temperature of the heat sink bleed air at the exit of the liquefier heat exchanger, and the heat removal required for oxygen liquefaction.

2.0 Integration Issues

Based on the liquefier design trade studies conducted by ADL, it was determined that the amount of bleed air required for liquefier operation ranged from 1.2 to 1.9 lb/min. The variation in flow rate is related to the selected design condition at the exit of the liquefier heat exchanger. An MSOGS unit was recently flight tested as part of the Tactical Life Support System demonstration on an F-15 aircraft. This unit required a flow rate of 2 lb/min and its installation in the F-15 and consequent flow extraction proved to have minimal effect on the aircraft environmental control system (ECS). This fact was verified by computer simulation and evaluation of flight test data. It is believed that retrofit installation of a 4 lb/min HOS in the F-15 and other aircraft will render no adverse effects either on the operation of the aircraft ECS or on aircraft performance. The HOS, with its low weight and volume characteristics, provides an excellent alternative to onboard stored oxygen. This system, because it produces oxygen at conventional pressure, will be compatible with either the CRU-73 or BRAG regulator. Appendix 1 examines the F-15 retrofit installation of the HOS in detail.

3.0 Bleed Air Availability

The quantity and thermodynamic state of the ECS bleed air supply is given in Tables 1 and 2 (pp. 80-81) for generic fighter and bomber missions, respectively. These conditions, as well as ECS bleed air location, were chosen based on design specification values for a typical (NGL) MSOGS unit (i.e., inlet pressure of 25 to 90 psig, required performance from 0°F to 100°F, operating to 160°F). The conditions from the fighter mission (Table 1, p. 80) most closely matching the required MSOGS conditions are at the exit of the secondary heat exchanger. A heat exchanger may be necessary prior to the MSOGS in the case of the bomber mission.

4.0 Excess Cooling Potential

Depending on the design and baseline operating state of the HOS, a range of options exist for generating excess cooling potential. For instance, the bleed air stream at the exit of the liquefier section, disregarding the low pressure, has excellent cooling potential. Also, the LOX, after extraction from the dewar, could be used as a heat sink prior to delivery to mask. Analysis of the HOS performance, as well as overall aircraft ECS performance,would have to be done to determine the worth or advantage of external use of excess cooling from the HOS. To determine where to tap off the HOS for additional cooling, the following questions must be answered or trades conducted:

1. What are the payoffs and/or weight penalties associated with increased cooling capability at the expense of increased sizing in heat exchangers or turboexpander?

2. What are the payoffs and/or weight penalties associated with increased cooling capability achieved through increased MSOGS output?

Additional cooling is necessary in present day and future electronics exhibiting high power density. Specific needs include cooling for avionics, advanced sensors, and applications for VHSIC (very high speed integrated circuit) and VLSIC (very large scale integrated circuits). The HOS could also be designed to use the vent bleed air as a bootstrap to precool the inlet bleed air. Use of the hybrid system as a bleed air conditioner and additional details on specific application of the excess cooling potential are found in Appendix 1 (p. 82).

5.0 Boeing Report Conclusions

The HOS being developed by A.D. Little, by processing the concentrated oxygen from the MSOGS and storing it as a liquid, preserves the conventional reliability and convenience of stored onboard oxygen while reducing the logistics burden of stored onboard LOX. The HOS, with its minimal bleed air requirements, can be used as a retrofit solution to LOX in current aircraft and as an alternative solution to LOX in future aircraft. The HOS also provides an excellent source of clean conditioned bleed air and inherently possesses potential for use in aircraft/avionics cooling.

4. Phase II: Laboratory Demonstrator Design

4.1 Laboratory Demonstrator Objectives

The purpose of this program is to develop and demonstrate a laboratory demonstrator HOS, as discussed in Chapter 3. The generation of oxygen from an MSOGS is to be coupled with a compressed air open loop refrigeration system. The compressed air will contain water vapor, trace gases, and possible chemical contaminants. These condensible gases are not too different than those experienced in stationary air liquefaction plants, but could be a considerable challenge for a lighter weight, compact mobile unit. Water vapor and other gases, which will condense at liquid nitrogen temperatures, could compromise the performance of the refrigeration cycle, if not adequately managed.

The objectives of the laboratory demonstration program are to:

- demonstrate cooldown of the system to the design temperature.
- demonstrate the production rate of LOX as a function of the amount of the supply bleed air flow. (Oxygen liquefaction (grams/second liquefied) with bleed air consumption required (grams/second))
- observe frost build up by monitoring the flow rate and pressure drop across the high pressure side of the heat exchanger.
- determine the feasibility of a deriming cycle to maintain free and clear refrigeration operation.
- determine the concentration of oxygen delivered from the storage dewars.

4.2 System Schematic and Major Commercially Available Components

Commercially available components were used throughout the system to reduce the overall cost. The demonstrator design was dictated by the performance of available heat exchangers and expanders.

4.2.1 System Schematic The system schematic is shown in Figure 5. The system consists of commercially available heat exchangers and components to simulate the reverse Brayton cycle selected in Phase I. Two 5-liter stainless steel dewars are shown, which are filled sequentially as outlined in Chapter 3.

4.2.2 Heat Exchanger The process and liquefaction stage heat exchangers are the central liquefier components so far as size and weight are concerned. Ideally, an actual aircraft HOS would require a lightweight stainless steel heat exchanger. A parametric analysis (Table 8) of the size and performance of the lightweight stainless steel heat exchanger can be performed through the selection of the temperature at station 4 (SW1) (SW or switch). This temperature dictates the sizing of the heat exchanger and the amount of bleed air required to liquefy the design flow of oxygen set at 40 LPM (NTP). An explanation of the calculation follows:

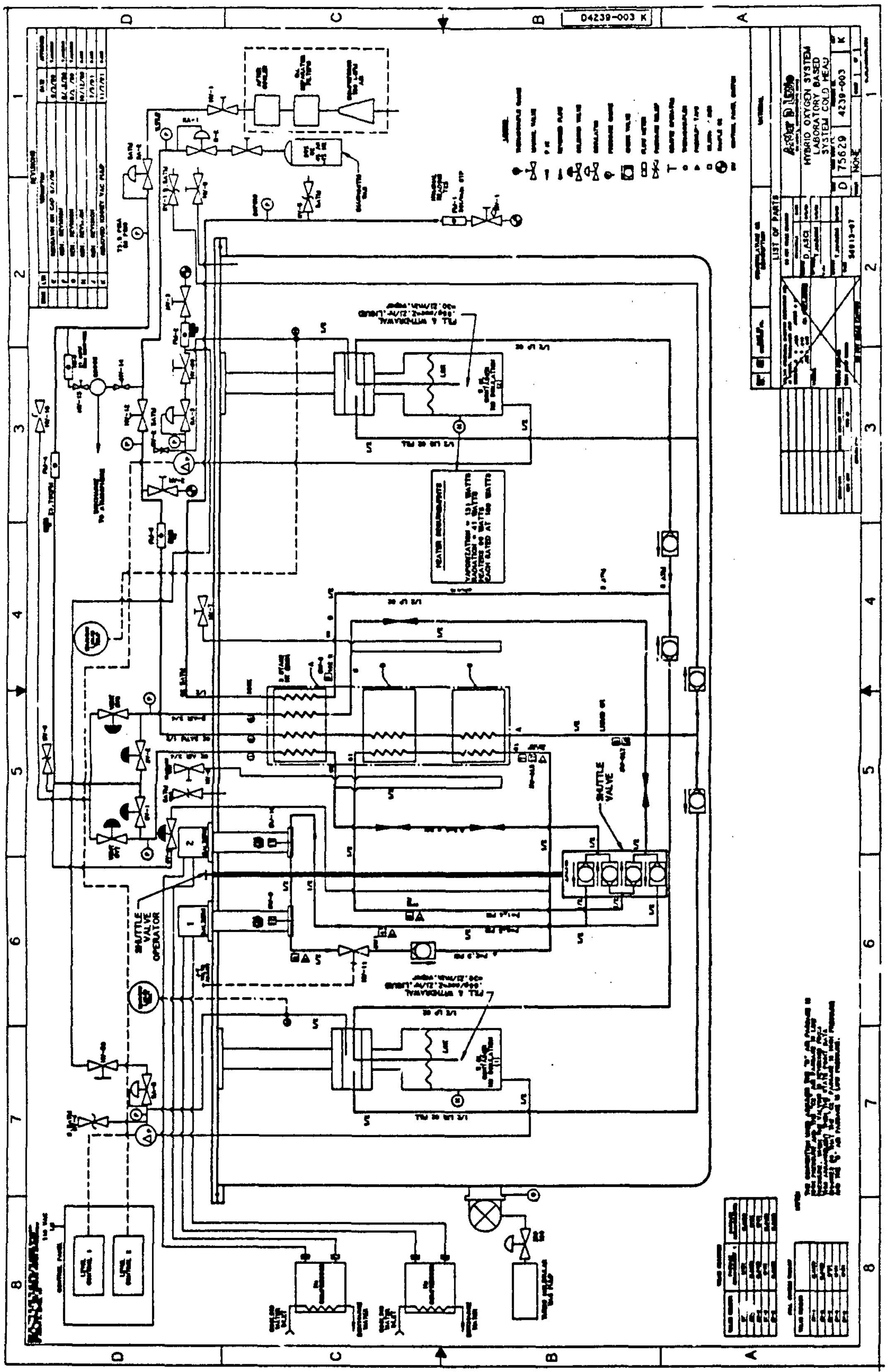


Figure 5. System Schematic.

Table 8. Hybrid Oxygen Component Sizing

08 jan-88 File Hybrid-H wk1 Hybrid Oxygen Component Sizing

02 09 PM

			2.00 " X	4.00 "			
			2.00 " X	1.50 "			
STREAM		O2	HI P AIR	HI P AIR	LO P AIR	O2	LO P AIR
T KELVIN:		300	293.3	300	293.33	113	94.511
Enthalpy(j/g)		272.133	420.917	426.705	420.917	78.104	217.88
GRAMS/SEC		0.668	0.576	13.411	12.835	0.668	13.411
T KELVIN:		113	94.511	113	94.511	102	84.47
Enthalpy(j/g)		78.104	217.881	232.337	217.88	-112.462	207.387
	REQUIRED CAPACITIES						
Duty Q (btu/hr)		441.97	398.80	8888.74	8886.39	434.09	479.8(
Effectiveness		0.9633		0.9637		0.3839	
M*C (btu/hr-f)		1.3187	1.1193	26.5202	24.9371	22.0172	26.6634
M*C minimum (btu/hr-f)		1.1193		24.9371		22.0172	
Cmin/Cmax		0.8488		0.9403		0.8257	
NTU		10.60		15.90		0.59	
UA Required (btu/hr-F)		11.86		396.58		13.03	
	PROPERTIES						
Viscosity	(lbm/hr-ft)	0.037	0.033	0.033	0.033		
Cp	(btu/lbm-f)	0.2479	0.2440	0.2483	0.2440	4.1386	
K	(btu/hr-ft-f)	0.012	0.01	0.01	0.01		
Density	(gr/cm3)	0.00586	0.00899	0.00899	0.00237		
Prandlt No.	(1)	0.74	0.73	0.73	0.73		
	CORE CHARACTERISTICS						
Width (in)		2	2	2	2	2	
Passage height		0.1	0.1	1.9	1.9	0.5	
Number of passages		2	2	38	38	10	2
Free Flow Area (sq in)		0.0922	0.0922	1.7518	1.7518	0.4610	0.922
Mass flux (lbm/hr in2)		57.7045	49.7572	60.9734	58.3546	11.5409	115.849
Reynold's No		449.1593	434.2443	532.1319	509.2769	89.8319	1011.050
h (btu/hr -in2-f)		0.6117	0.5335	0.5967	0.5744	4.8374	0.808
fin ML		0.5682	0.5306	0.5612	0.5506	1.5978	0.653
fin effectiveness		0.9047	0.9156	0.9068	0.9099	0.5766	0.878.
total effectiveness		0.9523	0.9578	0.9534	0.9549	0.7883	0.939
UA/lenght(btu/hr-f-in)		8.9480	7.8489	166.0125	160.0770	292.8694	116.594
Overall UA/inch		4.1812		81.4954		83.3943	
Lenght Required inchs		2.8375		4.8663		0.1562	
LONGITUDINAL CONDUCTION							
Area header bars sq.in.		0.010		0.190		0.075	
Area fins sq.in.		0.016		0.298		0.118	
Area braze sq. in.		0.000		0.009		0.004	
Area side plates sq in		0.160		0.160		0.160	
Area plates/braze sq.in.		0.033		0.623		0.164	
(ka)header		0.071		1.349		0.533	
(ka)fin		0.111		2.115		0.835	
(ka)braze		0.096		1.824		0.720	
(ka)side plate		1.136		1.136		1.136	
(ka)plates,splitters		0.307		5.833		1.535	
(ka) ALL		1.721		12.257		4.759	
Longitudinal loss ratio		0.0383		0.0079		0.1153	
Corrected Effectiveness		0.9277		0.9563		0.3669	
	ITERATION OF LENGTH						
Length Multiplier		2.50		1.40		1.30	
Final NTU		26.5000		22.2645		0.7691	
Inc Effectiveness		0.9972		0.9790		0.4515	
Iteration Parameter		1.0194		1.0102		1.1288	
Final Core Length inches		7.0938		6.8128		0.2030	
Pressure Drop psi		0.1485	0.0741	0.0901	0.3247	0.0007	0.021
	SIZE AND WEIGHT						
Add headers inches		3.000		3.000		3.000	
Total length inches		10.094		9.813		3.203	
Weight in lbs.		0.624		3.548		0.471	

1. Temperature at Station 4 is selected.
2. The ratio of bleed air mass flow rate to oxygen mass flow rate is calculated as the enthalpy ratios of the latent heat of vaporization of oxygen divided by the enthalpy difference of Station 4 minus Station 3. The sensible cooling of 6A to 7 is accomplished by the interchange with existing cold oxygen vapor.
3. The pounds/hour bleed air is calculated knowing the oxygen flow rate (40 LPM (NTP)).
4. An inlet temperature is selected, 300°K.
5. The required heat exchanger effectiveness (E) is calculated as 300 - 120/300 - T4.
6. The number of transfer units (NTU) is calculated from the formula 1/(1-E), resulting in a required UA equal to NTU times MC_p (mass flow rates times heat capacity); overall heat transfer coefficient U times area A.
7. A Reynolds number based on the hydraulic radius is calculated and used to estimate the heat transfer coefficient for the selected heat exchanger. For the purposes of this analysis, a plate fin compact heat exchanger on page 209 of Kays & London, Compact Heat Exchangers, McGraw Hill, 1961, was used.
8. The heat transfer coefficient in British thermal units per hour (Btuh)/sq ft°F derived from the fluid properties, Reynolds number and heat transfer correlation is calculated. The required overall heat transfer coefficient is assumed to be one-half of each (the single-sided heat transfer coefficient).
9. The required heat transfer area as calculated by dividing the required UA by one-half H. This leads to the calculation of the heat exchanger size and weight directly from the Kays and London heat exchanger parametric data.

   An identical series of calculations are made for the liquefier section of the heat exchanger. The entering temperature of the cold side to this portion of the heat exchanger is line #1, and the outlet condition is saturated liquid oxygen at atmospheric pressure and a temperature of 90°K.

These temperatures and flow rates set the heat exchanger performance, and assuming the heat transfer coefficient is governed by the same value as the gas heat transfer coefficient, the heat exchanger portion for liquefaction is calculated.

An additional heat exchange is required to precool the oxygen with the exiting nitrogen stream. Its size is calculated in the same fashion.

For the laboratory demonstration, the desired heat exchanger performance was achieved through the use of a commercially available aluminium cryogenic heat exchanger, as custom stainless steel heat exchangers were not available. The aluminium cryogenic heat exchanger was necessarily longer and heavier than a custom flight heat exchanger. This difference is a consequence of the extremely large longitudinal temperature difference that the heat exchanger must support. To counteract the adverse effect of high thermal conductivity of aluminium (nearly 16 times more conductive than stainless steel) on the end-to-end conduction, additional heat exchanger length is needed amounting to 4 times the length of a flight stainless steel unit. The added length increases the fluid pressure drop so that enlarged cross-sectional areas are needed, which again raises the size and weight of the unit.

4.2.3 System Deriming Function Bleed air from the engine is supplied to both the MSOGS and the liquefier refrigeration cycle. Condensibles and contaminants contained in the bleed air will be deposited in the process heat exchanger. Deriming techniques are needed to manage these condensibles in cryogenic liquefaction systems and can be very effective depending on the composition and amount of contaminant.

Deriming is accomplished by switching the heat exchanger flow path by changing the air flow solenoid switch positions and the manual 4-way reversing valve.[7] Solenoids SV1 and SV8 (Figure 5) are operated together with the reversing valve in the "up" position, and SV2 and SV7 are set to the opposite condition. Reversing the flow is accomplished by changing the switch settings and the reversing valve. At each cross section, the heat exchanger suddenly experiences a drop in dew point on what was originally the high pressure side because the flow has switched from 5 ATM 100% saturated air to 1 ATM dry air.

Engine bleed air is simply compressed ambient air. Water vapor and some carbon dioxide (CO_2) represent the major condensibles which must be managed by the refrigeration system. The amount of water vapor and CO_2 deposited will depend on the concentration in the ambient air at altitude and the amount of water removal in the ECS. The low air temperatures at nominal flight altitude (25,000 and above) result in low humidity ratios relative to humidity at ground conditions but still contain substantial amounts of water vapor. The maximum condensable content (saturated) at altitude is given in Table 9.

Table 9. Mass Fraction Concentration of Condensibles

	Maximum Concentration (over 25,000 ft Altitude)	Typical Concentration in Lab Test
Water vapor	.0010	.023
CO_2	.00031	.003

One of the major functions of the laboratory test program will be to evaluate the effect of high levels of water vapor and CO_2 on the air cycle (oxygen and nitrogen) refrigeration systems. The principal effect of condensibles and contaminants on the heat exchanger will be deposition of frost on the heat exchanger and subsequent reduction in mass flow rate due to the increased flow resistance and pressure drop.

4.2.4 Cold Head and Throttle Valve As described in section 3.3, a work-producing expansion device is necessary to achieve the refrigeration. Traditional reciprocating expanders operating at relatively low speeds would be enormous and impractical in the flight environment, hence, a miniature gas bearing turbine expander was identified as the appropriate component to achieve the desired expander performance, but the cost of such a development unit was beyond the budget of this program (see Table 10). For this program a simulation of the expander performance was devised using a cold head in series with an expansion valve. Figure 6 shows the design condition of a turboexpander and that of the cold head-throttle valve series. The simulation has the identical thermodynamic end points but is a different process. Two expansion processes are shown in the diagram. An ideal isentropic expansion and a realistic 70% of isentropic (ideal) expansion are shown. The isentropic expansion offers substantially greater refrigeration but can not be achieved. The nominal design point with a 70% expander will bring the bleed air to the saturation condition at about 85°K, which is sufficiently cold to liquefy pressurized oxygen.

7 The four-way reversing valve was added later in the program (see Figure 10).

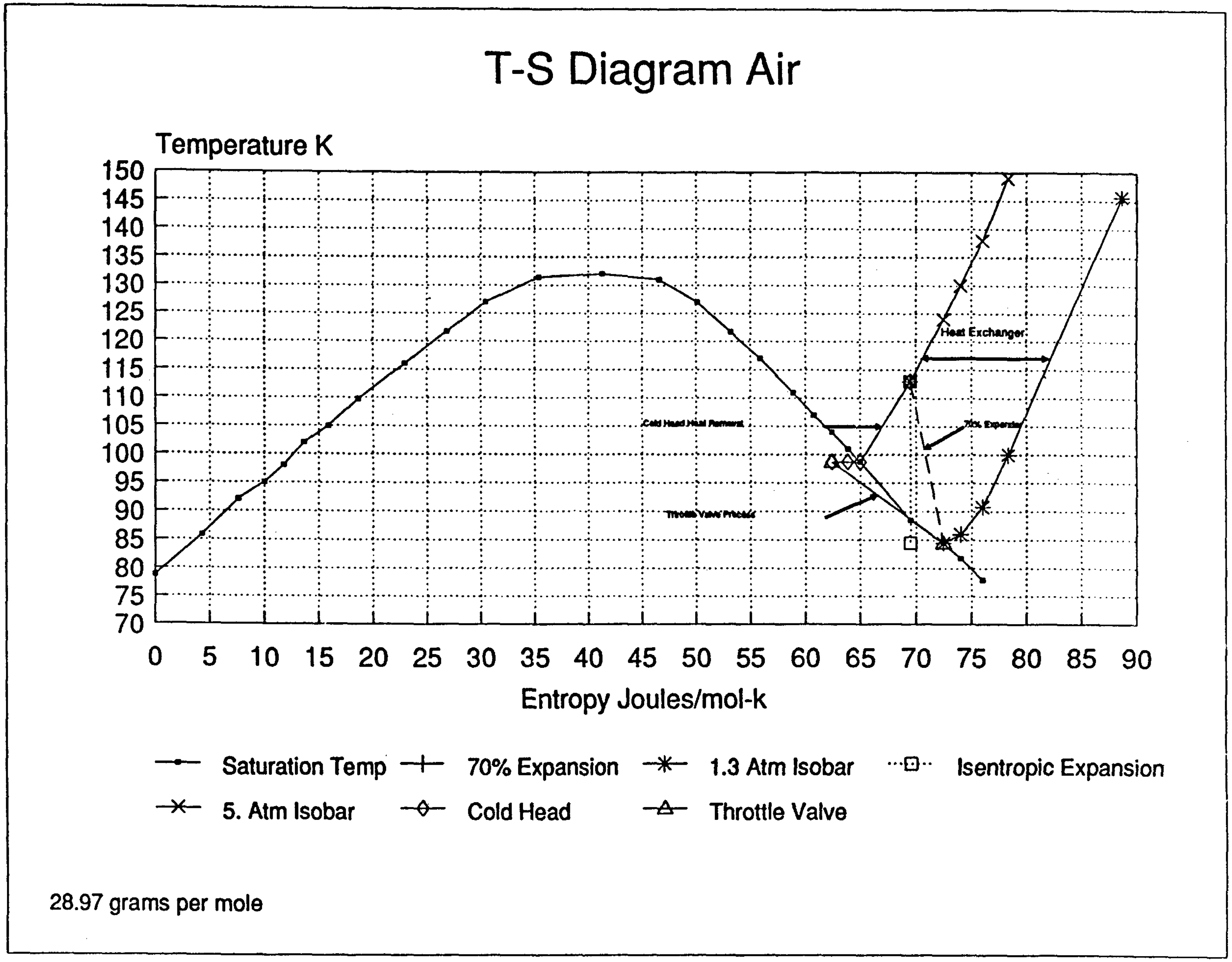


Figure 6. Temperature Entropy Diagram of Process.

Table 10. Expander Comparison

Manufacturer	Cost	Delivery Time	Weight	SIZE Dia. Length	η Max	Watts
Koch Process Systems Reciprocating Expander Model 1600	over $50,000	16 wks	800 lb	34-1/4" 70"	50%	367 max.
Creare Turboexpander						
A. 18 watt	$100,000	12 wks	10 lb	4" 11"	75%	18
B. 100 watt	$350,000	20 wks	10 lb			100
C. 370 watt	$500,000	24 wks	10 lb			370
Sulzer Bros. Turboexpander TGL-22-11/B2	$80,000	8 mos	90 lb	10" 32"	~60%	~300
Balzer - 2 Cold Heads and JT Valve	$60,000	1 mo	40 lb	10" 12"	NA	330

Two Balzers Helium Cryogenic Refrigerators and a Koch Process J-T valve were selected for the application. The two cold head units have a total refrigeration capacity of 330 w at about 80°K at the cold head. With the proper design of the cold head exchanger the cold heads will produce the required refrigeration.

4.2.5 Heat Balance Table 11 shows the heat leaks on the heat exchangers, and Table 12 summarizes the total heat balance. At the design (Table 12) flow rate of oxygen (.66 g/sec), 256 w of refrigeration are needed which requires 357 w of cooling at the cold head. The cold head exchanger operating at 85°K must have 6.2 NTU's. Table 12 shows the effects of running at reduced oxygen flow rate on the heat exchanger performance. For instance, at .55 g/sec, a cold head heat exchanger of 1.1 NTU is required.

Table 11. Heat Leak Into Cold End In Watts

Component	Conduction	Radiation	Total
Stem Valve	2.5	2.5	5
Piping- Air HP	.1	3.4	3.5
Piping-Air LP	.1	3.2	3.3
Piping-O_2-HP	.1	2.8	2.9
Piping-O_2-LP	.1	1.6	1.7
Pressure Relief Line	.1	2.2	2.3
Defrost Line	1.4	3.4	4.8
Pressure Taps	.2	3.6	3.8
Heat Exchanger		2	2
Heat Exchanger Supports	7.2	.8	8
Total w/o Dewars			37.30

The expected heat leak into the cold end of the system (exclusive of the dewars) is given in Table 11, which shows a predicted value of about 37 w. About 26 w of this heat leak flow into the heat exchanger and cold end and are included in the O2HXLQ.WK1 model (Table 12) which was used to size the cold head heat exchangers.

4.3 Piping Diagrams[8]

4.3.1 Drawings The piping diagrams for the system are given in Appendix 7.3.1. A photograph of the main elements is given in Figure 7. This figure shows the cold heads, cold end plumbing, and process heat exchanger all attached to the cover plate of the vacuum vessel. The dewars are not shown, but they attach to the two long stem flanges shown on either side of the heat exchanger.

4.3.2 Pressure Losses The piping diagrams specify the fluid components and piping lengths which, in turn, allow for the calculation of system pressure drop. Table 13 shows the calculated pressure drop through the system. The total pressure drop is estimated to be about 6 psi which is well within the 10 psi budget selected for this design.

8 The discharge of MSOGS and liquefier are attached to the same vacuum manifold.

Table I2. Heat Exchanger Design.

					Cp equivalents		P(atm)	j/gram-K
****** Ua-HX	0.72		hx-1b	o2	113 to 102 k		5.00	0.9973
file:02hxlc UA-HX	16.73	w/k	hx-1c	Liq O2	latent heat		5.00	199.70
	Heat Leak	Effec	hx-1a	o2	300 to 113		5.00	0.94
	Qleak	dE	hx-1a	air	300 to 113		5.00	1.04
H1a	21.40	0.01	c-hd	air	113 to 84		5 to 1	0.87
H1b		0.00	hx-1c	air	84 to 94		1.30	1.04
H1c		0.00	hx-1a	air	94 to 300		1.3	1.02
ColdH	5.00	0.02						
	26.40							

Input Tliq= 99.00

	E-HX-	O2 Flow g/	Air Flow g/sec	Q(liq) watts	Iterator	Ta1	UA vap NTU LI HX 1C + 1B		E	Iterator	Tlow K	T out Liquif	T out Vapor
		0.66	13.41										
Design Point →	0.968	0.66	13.41	130.80	113.75	113.72	0.48	1.21	0.69	85.41	85.51	94.85	95.54
	0.968	0.61	13.41	121.82	113.39	113.39	0.464	1.21	0.69	86.44	86.44	95.14	95.76
	0.968	0.55	13.41	109.84	112.90	112.94	0.44	1.21	0.69	87.70	87.69	95.53	96.07

COLD HEAD HX

Q o2 watts T	Q watts	Tch K	E	NTU	Tout warm
254.30	357.23	85.17	1.00	6.20	293.46
236.83	342.38	80.71	0.83	1.80	293.46
213.53	322.58	74.77	0.67	1.11	293.47

File: 02HXL.WK1

Range Name: HX

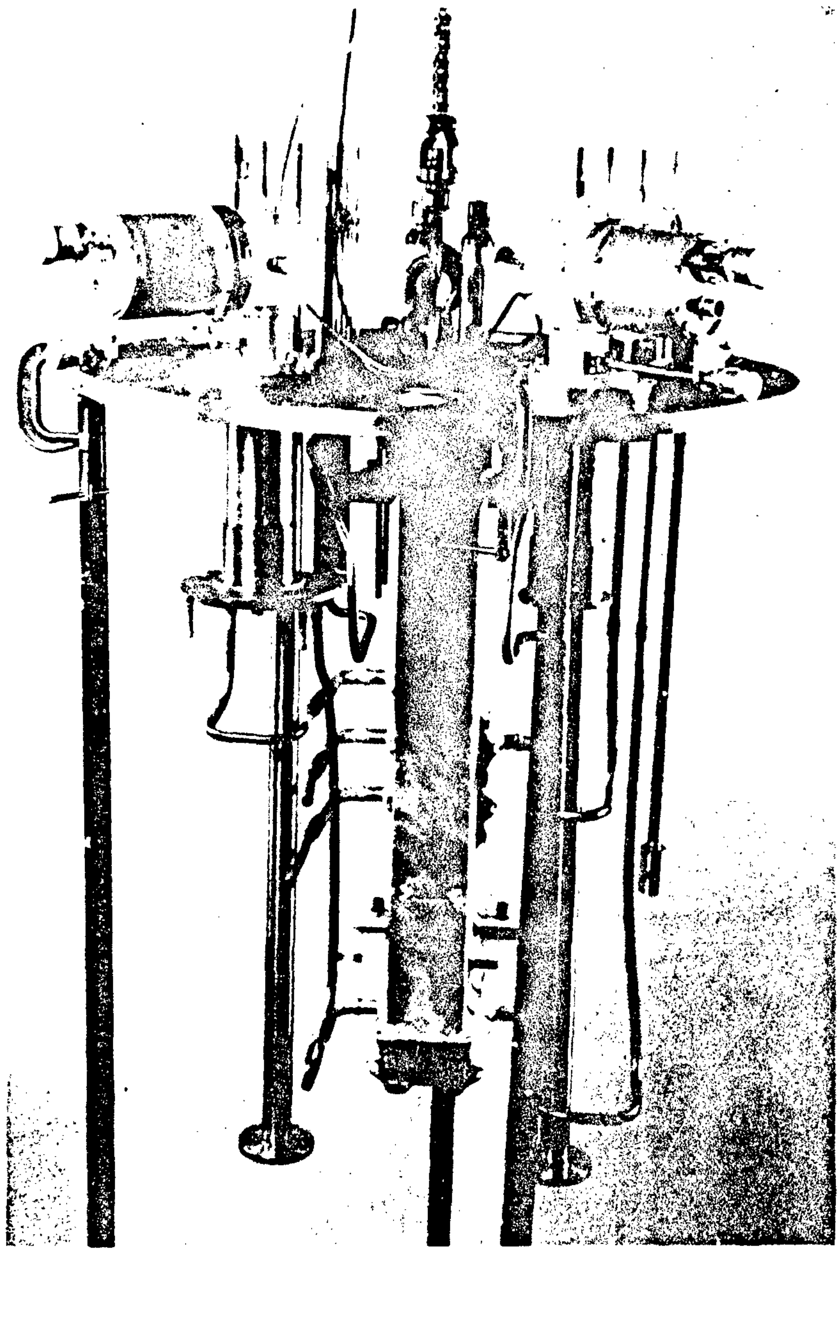


Figure 7. Main Refrigeration Elements (Dewars Not Attached).

Table 13. System Pressure Losses In PSI

Component or Piping Section	Dia."	Len."	ΔP (psi)
Air-Low Pressure			
From Cold Head to HX	.5	48	2.3
from HX to check valve	.5	40	1.4
Check valve	.5		.14
from Check valve to Hx	.5	24	.8
from Hx to Vac Cover	.75	24	.1
Total			4.74
Air-High Pressure			
from Vac Shell to HX	.5	24	.01
from HX to Check valve	.5	12	.1
Check valve	.5		.2
from Check valve to cold heao	.75	121	.5
Total			0.81
O_2-High pressure	.5	94	.05
O_2-Low pressure	.5	54	.11
Total			.16
O_2 Needle Valve			0.14

4.4 Mechanical System

The mechanical system layout is shown in Appendix 7.3.1.

4.4.1 Heat Exchangers and Liquid Storage Layout The heat exchanger is four 36-in.length sections as seen in Figure 8. Insulated stand-off mounting of the heat exchanger, dewars and plumbing follow standard cryogenic design practice to minimize heat leakage into the cold components.

Two 5-liter storage vessels are included to accommodate a range of liquid storage scenarios.

This drawing is not to be used for making reproductions thereof, or for making any apparatus based thereon, without first obtaining written authorization of Arthur D. Little, Inc.

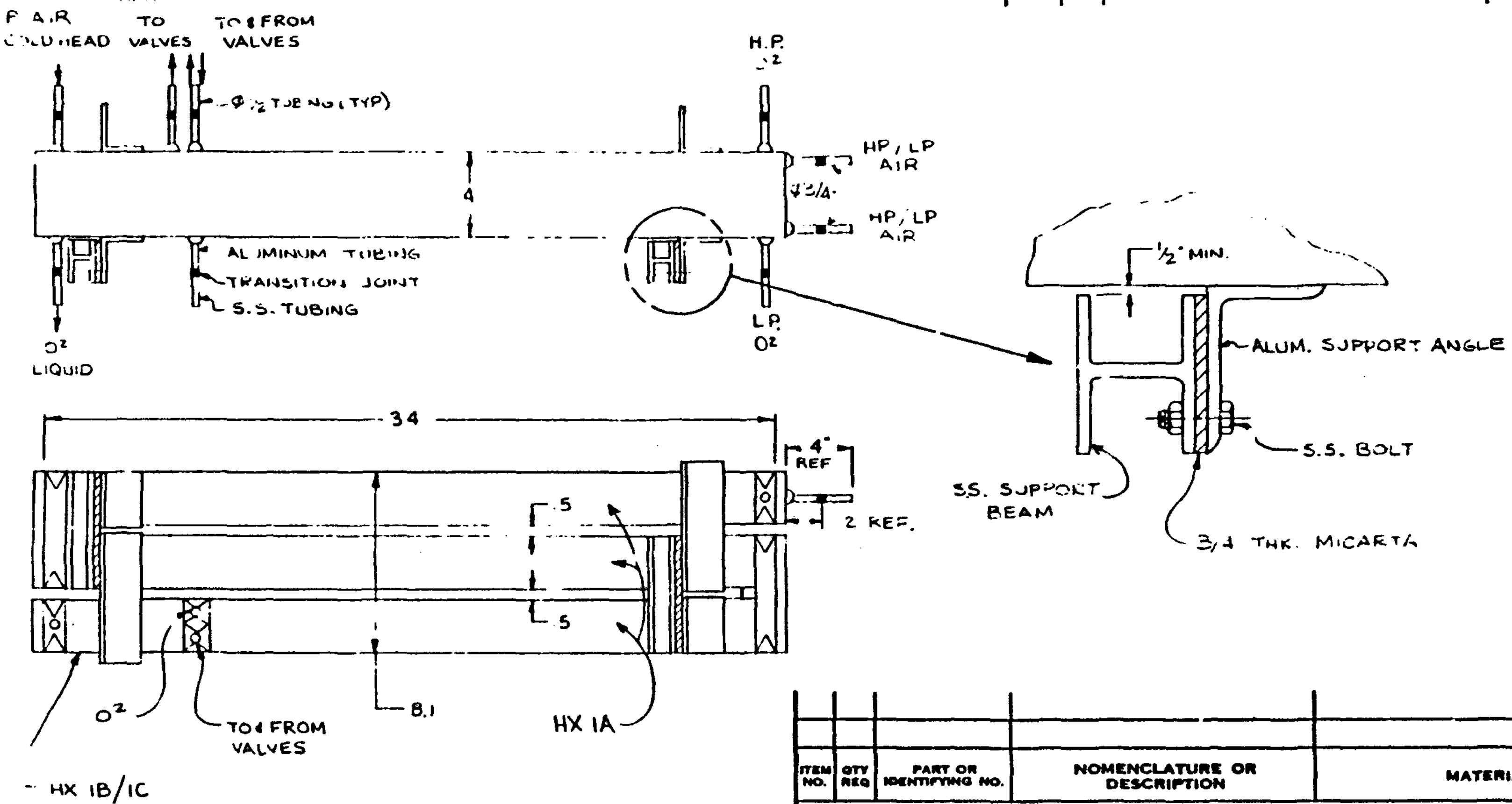


Figure 8. Heat Exchanger and Liquid Storage Layout.

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

ITEM NO.	QTY REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL

LIST OF PARTS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
DECIMAL .XX = ±.010 .XXX = ±.005
FRACTIONAL ±1/64
ANGULAR ±1°
FINISHED SURFACES RMS
BREAK SHARP CORNERS
DO NOT SCALE THIS DRAWING
MATERIAL

ISSUE DATE:
DRAWN D. ASCI 6-2-86
CHECKED T. Ma... 6-...
APPROVED

Arthur D Little Inc.
CAMBRIDGE, MASSACHUSETTS 02140

HX IA, IB, IC
HYBRID OXYGEN SYSTEM

SIZE B | CODE IDENT NO. 75629 | DRAWING NO. SK 6288 | REVISION
CASE 56913-05 | SCALE NONE | SHEET 1 OF 1

NEXT ASSY | USED ON
APPLICATION

ADL-218-478-3M

4.4.2 Piping, Flow Controls and Instrumentation The piping layout is given in Appendix 7.3.1. The piping approach incorporates the refrigeration cycle as well as the deriming cycle. A discussion of the controls and instrumentation are given in section 4.5. The piping analysis was outlined in section 4.3.

4.4.3 Concentrator An Essex concentrator will be used as provided by Essex Cryogenics, St. Louis, MO. The layout of the unit is shown in Figure 9 and the performance characteristics of the unit are contained in Appendix 7.4.

4.4.4 Compressor A compressor sized at 60 standard cubic feet per minute (SCFM) and 100 psig pressure will be used to provide the supply of bleed air to both the liquefier and the oxygen generating system.

4.5 Electrical

The diagrams in Appendix 7.3.3 (electrical schematic) shows the electrical system layout, including instrumentation sensors and controls for the operation of the compressor, vacuum and expander subsystems.

The instrumentation consisted of silicon diodes and thermocouples for the temperature measurements and capillary tubes for the pressure measurements. Table 14 summarizes the instrumentation selection.

Table 14. HOS Instrumentation

Flow Meters	Fisher-Porter, Model 10A 2700 (various diameters)
Regulator	Tescom Pressure Controls
Thermocouples	Arthur D. Little, Inc.
Diodes	Lake Shore Cryotronics
Pressure Taps	ADL Capillary
Manual Valves	Essex Industries
Pressure Gauge	1/2" NPT McDanial Controls
Hermetic Connectors	Allied Amphenol Products

<u>Silicon Diodes</u>

Silicon diode temperature sensors were used because precise temperature measurements were required. We chose Lake Shore Cryotronics DT-470-DI-13-4L sensors which were individually calibrated in the 75 to 325 K range at an accuracy of 50-75 mK. These diodes were mounted on specially designed copper disks which have protruding sections into the gas flow. Diodes in pairs at each measurement location were used as a precaution in case one of the diodes lost its signal during testing.

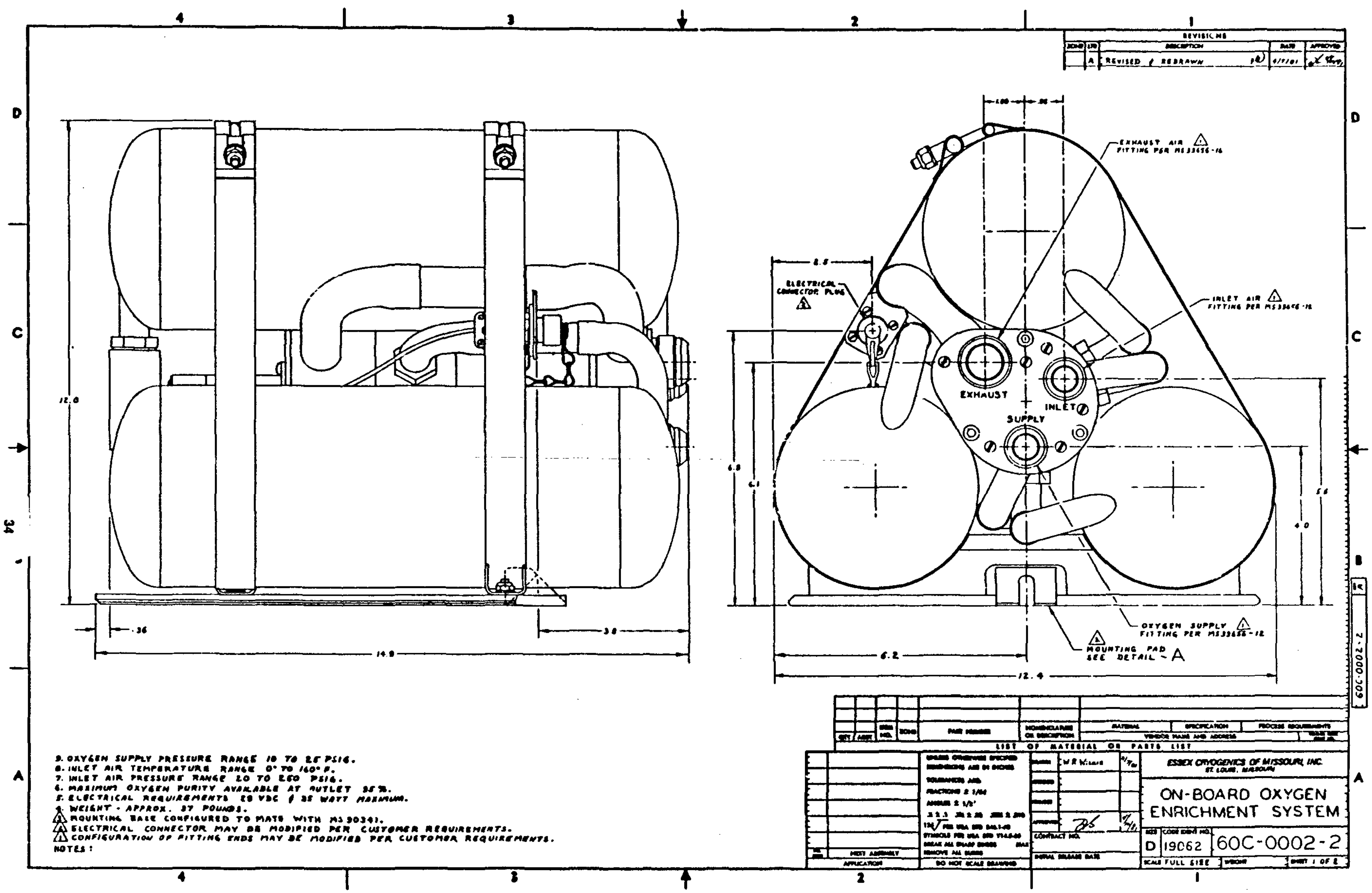


Figure 9. Layout of Onboard Oxygen Enrichment System.

A Lake Shore Cryotronics readout was used to determine the voltages of each station as a function of time. Twenty silicon diodes were used, consisting of a diode pair at each of nine locations (the inlet, intermediate, and exit of the heat exchanger streams) and two spares.

Thermocouples

Standard type "T" thermocouples are used at the warm end of the heat exchanger and on the dewar vents. The thermocouples were mounted to copper sleeves which were bent over the pipes at the desired locations. The thermocouple temperatures were recorded automatically with a Leeds and Northrop Strip-Chart Recorder.

Pressure Taps

Custom capillary tubes are used at locations where pressure measurements are desired. The taps were connected to a valving system with pressure gages to measure the pressure drops. For the HOS, we used six pressure taps (located at the inlet, intermediate, and exit of the heat exchanger streams).

4.6 Instrumentation

4.6.1 Temperature Five thermocouples and ten temperature sensing diodes were used in the system. Diodes were used principally at the cold end of the piping and thermocouples at the warm end of the heat exchanger. The selected diodes are Lake Shore Cryogenics DT-470-DI-13-4L sensors which were individually calibrated from 75°K to 325°K. The diodes are more precise at cryogenic temperatures with an accuracy of 0.1±°K, while the thermocouples are good to ± 1°K or ± 3°K @ 300 °K. The diodes were mounted on specially designed copper disks which have a section protruding into the gas flow. We estimate an uncertainty of absolute temperature of .2°K at 75°K with this method of measurement. The thermocouples are less expensive and more rugged; and were used at the warm end where there was not enough space to mount the diode disks as the thermocouples can be strapped directly on the gas tubing without being damaged.

The diode and thermocouple wires are routed through connectors in the cover plate. The diodes are connected to a single Lake Shore model 201 Thermometer with direct Kelvin readout, and selection of the sensor is done by a rotary manual switch. The thermocouples were monitored on a thermocouple strip-chart recorder reading directly in degrees centigrade.

4.6.2 Flow Rate Flow rates are determined by Fisher & Porter rotometer type flow meters. Three Model #10A4555x flow meters are used for the oxygen lines (FM-1, FM-2 and FM-6) and two for the air lines (FM-3 and FM-4). The typical meter accuracy is ± 2%. The design point reading of the meters is given below in Table 15.

Table 15. F&P Flow Meter Calibrations

Flow Meter	Pressure ATM	Design Flow Rate SCFM	% Scale
FM-1 O_2 Mask	1	1.09	72
FM-2 O_2 Vent	1	1.09	72
FM-3 MSOGS air	5	23.7	72
FM-4 Ref air	5	23.7	72
FM-6 O_2 In	3	1.09	41

An on-line oxygen concentration monitor was used at all three NV locations during all tests. The monitor is a Beckman Oxygen Analyzer, digital display with characteristics shown in Table 16.

Table 16. Beckman Oxygen Analyzer

Reproducibility	± .01 %
Response Time	7 seconds
Sample Flow Rate	250 cc/min
Output	Selectable DC & Alarm
Baromet[illegible]mp	± 1 % F.S.

The Beckman oxygen monitor will track the concentration of oxygen during specific operations and for specific functions:

- ***Dewar Filling***: oxygen percent is measured @ NV-2; in the event that the concentration falls below 90% the O_2 flow will be manually terminated (see section 4.7.4). Oxygen percent also is measured at NV-3 dewar vent.
- ***Dewar Oxygen Withdrawal***: the concentration was monitored at NV-1.

The data taken during the course of the tests suggests that the oxygen monitor read 2% to 5% high on occasion when compared to the expected oxygen concentrations from the MSOGS unit.

4.7 Safety Review

Operation and handling of high purity oxygen can be hazardous, and careful attention to safety at the design stage is necessary to guarantee safe operation.

4.7.1 Safety Review Board A preliminary safety review was conducted as part of the Phase II design effort. A final safety analysis was conducted prior to assembly of the oxygen system plumbing and after parts were prepared. Members of the safety review board were:

- W. David Lee - Program Manager
- Thomas Maimoni - Manufacturing Specialist
- Arthur Post - Senior Cryogenics Engineer
- R. Warren Breckenridge - Senior Cryogenics Engineer
- Paul Croce - Senior Safety Engineer
- Tom McKelvey - Senior Safety Engineer

Safety action items and their resolutions are given in the next several subsections.[9]

4.7.2 Materials Inspection of all oxygen handling components and confirmation of oxygen rating were conducted and summarized in Table 17.

9 Smoking was not permitted in the pilot plant, and all oxygen was vented out of the building.

Table 17. Safety Inspection List

Component	Symbol or No.	Confirmation
O_2 Pressure regulator valve	R-2	Supplied with O_2 Bottle
O_2 Pressure regulator	RA-1	Oxygen Regulator
Oxygen Pressure gages	5	316 SST Clean for O_2
30 LPM stp flow meters	4	316 SST Clean for O_2
2.2 lph 3 ATM liquid check valves	4	O_2 Service Essex Cryogenics
Liquid O_2 Dewars	2	316 SST Clean for O_2
Asco vent solenoid valves	2	O_2 Service Asco
Magnehelic Liquid level gage	2	Dwyer Cleaned for O_2
Altec Heat Exchanger Core	1	Inspection Certificate (IC)
Stainless .75 OD tubing		IC
Stainless .5 OD tubing		IC
Relief valves 5.5 ATM	5	316 SST cleaned by ADL
Needle & Hand valves	NV-3,NV-2 NV-1 HV-12	316 SST cleaned by ADL

All valves and pressure gages were calibrated on bench-top tests with an oil-free nitrogen source.

4.7.3 Pressure Certification The following components were certified or checked for the pressure rating and are summarized in Table 18.

Table 18. Pressure Certification

2 Oxygen Dewars	100 psi Pressure Vessel
Pressure relief valves on vacuum vessel 1-2 psig	The cover plate weight of 550 lbs and 34 in dia represents a .6 psig lift off pressure relief which is desirable.
Set all 4 oxygen line relief valves to 5.5 ATM	Calibrate relief valves #1,#2,#4,#5 to 5.5 ATM with oil free N_2.
Check RA-3, RA-5 to confirm can withstand 5 ATM,	100 psig 316 SST cleaned for O_2 service

Note: RV3 and RV1 may not be necessary but will not harm the apparatus.

The vacuum cover plate is not fastened to the vessel and will release vessel pressure above about .6 psig. This safety feature will accommodate unexpected oxygen or pressurized air release in the system within the vacuum chamber.

4.7.4 Modes of Failure *Liquid Level Failure* Failure of the magnehelic gage to properly register the liquid level plus miscalculation of the accumulated liquid (using the differential flow rate from FM-6 minus FM-2) may result in overfilling the dewars. An overfill protection temperature sensor is located on the oxygen vent line. During filling the sensor will be monitored by the operator to be sure that it is well above the saturated LOX temperature, to

prevent venting of LOX which would be a hazard. When a temperature close to 103 K is detected, the liquid fill will be discontinued by either switching :o the other dewar or shutting HV-12.

The safety review committee recommended the addition of a high liquid level interlock on the supply solenoid. The project team has decided to monitor the liquid level manually and not incorporate the automatic control because of budget limitations.

Similarly automatic shutdown of the dewar heaters (see section 5.1) was recommended, but because of budget limitations it was decided to carefully monitor the dewar vent line pressure manually and control the heaters manually.

Hazard Signals The test system has been designed to provide sensor da[illegible] for evaluation of the performance. A number of sensors provide warning of a potentially hazardous condition, which will require human response as summarized in Table 19.

Table 19. Hazard Signals (Manually Monitored)

Monitor	Action
Loss of Vacuum @ HV-5	If sudden pressure rise occurs, immediately terminate compressor operation and close HV-12 oxygen valve.
Dewar Fill level High; either Magnehelic or flow rate * time.	Terminate oxygen flow @ HV-12
Dewar Fill level High; T_{11} or T_{18} ~ 103 °K	Terminate oxygen flow @ HV-12
Dewar vent pressure rise above 5 ATM	Terminate heater input
O_2 concentration drops below 90% @ NV-2	Terminate oxygen flow @ HV-12. A drop in concentration could indicate cross contamination in the heat exchanger.

Valve Sequencing-Oxygen Errors in the operation of the oxygen valve sequencing have been examined. No hazardous conditions could be identified.

Overfilling of a dewar is a potential hazard and the procedures to avoid that condition and the emergency response are given in the previous section.

Another potential valve operation error is to open the 3 ATM fill switch to a dewar already pressurized to 5 ATM. In that event the dewar will blow-down through the vent line to the pressure set of RA-3 or RA-5. The only hazard in this situation is handling an instantaneous release of up to 5 liters of 5 ATM oxygen or 25 liters at 1 ATM. The interior space of the building was sufficiently large as to make this release inconsequential.

Valve Sequencing-Air Improper valve sequencing of the pressurized air system can occur in the following manner shown in Table 20.

Table 20. Valve Sequencing Hazards

Valve		
SV-1 open SV-2 open	system pressurizes to RA-2 level if SV 7&8 are closed; otherwise system releases through vent	no hazard
All sv closed	compressor dead headed; no flow	no hazard if compressor shut off in reasonable time (minutes)
RA-2 fails	air side could pressurize to compressor max of 132 psig	RV-6 should relieve the line at 5 ATM set point

MSOGS/Compressor Oil Flow Through Probably the most significant hazard is a release of oil vapor by the compressor into the MSOGS unit, creating an explosion hazard. Under normal conditions the maximum release of oil from the compressor is well below the levels which can be tolerated in the MSOGS.

In the event of a sudden failure of the compressor oil clean-up system, considerable oil will flow into the MSOGS unit creating an explosion hazard. We monitored the glass air flow meter FM-3 for signs of oil contamination in the event that the flow meter shows significant oil, the MSOGS should be disconnected from the air flow immediately.

Unexpected Oxygen Spill The following conclusions were made concerning a LOX spill:

- An instantaneous release of 10 liters of LOX in the pilot plant would raise the oxygen concentration by ≈1.6 %, which is not a hazard. While the local concentrations may be higher, the ventilation rates in the pilot plant should manage the vapor.
- A liquid spill on the floor could be a problem because of contaminants on the floor. A clean galvanized pan was fabricated and set on the floor to handle a spill.

5. Phase III: Hybrid Oxygen Laboratory Test Procedure and Results

5.1 Test Program

To meet the test objectives, a test program was implemented consisting of:

- Diagnostic tests (without oxygen) using research grade argon (Ar) to establish the operational procedures and any problems in the refrigeration system.
- Complete tests with MSOGS to measure oxygen concentration levels. During these tests, the MSOGS was vented to atmospheric pressure.

MSOGS system tests were conducted with an Essex MSOGS[10]. The unit was run with the bleed air refrigeration unit to produce about 2 liters of liquid in dewar No. 1. The flow was switched and the other dewar was filled with about 2 liters. Dewar No. 1 was allowed to self pressurize to 5 ATM and then liquid was withdrawn and the concentration measured. Self-pressurization required approximately 130 w of heat input. We calculated about 40 w of residual radiation heat input and have provided about 90 w additional heat with strip heaters wrapped on the outside of the dewar. Continuous gas concentration was monitored at NV-1 with a Beckman oxygen monitor. This instrument provides a continuous measure of the concentration percentage of the stream. The on-line oxygen instrument will provide a continuous check to detect major deviations from the condition when the chemical analysis samples were taken.

5.2 Test Procedure

The key processes for the safe and proper operation of the breadboard unit are given in this section.

5.2.1 Instrument and System Checkout Prior to operation, instruments and components were checked out by the test engineer and technician. All sensors were checked and the vacuum integrity of the pressure vessel was recorded. A room temperature pre-run vacuum of better than $.1 \times 10^{-4}$ torr should be achieved. With a cold heat exchanger, the vacuum should be 10^{-6} torr. The startup sequence is given in the next section.

5.2.2 Initial Cooldown (Room Temperature to 20°F) The initial cooldown is accomplished by alternate cold heat ON/OFF cycles to remove frost formation on the cold heads. The cold "ON" operation is initiated using SV1 and SV8. The JT valve is opened until a flow reading of 60 achieved at a supply pressure of 32 psig. Flow is continued until the air flow (FM4) drops by about 10% from a reading of about 60 to 50 with the same JT valve setting. The cold heads (SW 9) typically achieve a temperature of about 10°F. At this point, the cold heads are switched off until the cold head (SW9) is warmed up to equal the temperature at SW1. This operation is continued until temperatures SW 1, 2, 4, 8, 9 read below 20°F.

Once temperatures throughout the system are below 20°F, continue flow operation and valve down the JT until a 20 psi pressure differential is across the JT valve.

5.2.3 Final Cooldown (270°K to 100°K) During final cooldown, monitor the flow rate on FM 4, and when it drops by about 10% from 55 to 50, reverse the cycle. Observe the pressure taps, immediately after a cycle reversal, the high pressure side of the heat exchanger should rise approximately 10 psi to about 20 psi, representing a 10 psi frost formulation. During the defrost, pressure on the low pressure side should fall from 20 to 10 psig, at which point, another reverse cycle may be appropriate depending on FM 4 flow rate. Regular adjustment of the JT

---

10 The performance characteristics of the Essex unit are contained in Appendix 7.4.

valve must be made during the cooldown, as the density of the air is being reduced and the flow resistance drops. The target value should be about 35 psig on P3 and 15 psig on P7. (These values correspond to pressure tap positions 4 and 5, respectively, on Figure 5.)

Run Mode

Once SW4 diode has reached approximately 105°K, the oxygen can be started as it will begin to liquefy. Generally, open HV50 or Dewar No. 1 first and begin to fill it. Monitoring the dewar thermocouples is essential as it will indicate cooling of the vent in the dewar body itself. Considerable flow of oxygen is required before the dewar is chilled enough to allow for liquid build up. Generally the backflow regulators on the oxygen are set at approximately 15 psi gauge.

During the run mode, reverse the heat exchanger every 5 minutes when the flow rate on FM4 falls more than 10% of nominal or from 50 to 40.

5.2.4 Data Collection The test data are recorded on a personal computer (PC) spreadsheet according to the layout in Appendix 7.5.

5.3 Discussion of Test Results

The following tests were performed:

Four Ar diagnostics tests (not reported)

Seven oxygen tests

The Ar (not reported) diagnostic tests were performed in October and November 1989, at which point, the original check valves were replaced with hermetic check valves because of an unacceptable leakage to the vacuum. Subsequently, in the summer of 1990, the hermetic check valves failed as a result of sand from the heat exchanger fabrication lodging in the mechanisms. We suspect that the sand was either from the cleaning of the cold head heat exchanger or the main process heat exchanger by sand blasting. Finally, in the fall of 1990, a four-way sliding valve was designed and installed to overcome the check valve problems. The new flow schematic with the four-way reversing valve is shown in Figure 10. The modifications were completed in October 1990, and the oxygen tests were run.

A representation of system performance data recorded is displayed in Figure 11. The results of oxygen test No. 7 will be described for all six graphs as well as references made to the results of earlier tests. Test data for tests 1 through 6 are contained in Appendix 7.6.

5.3.1 Test No. 7 Results

Graph 1 - Cooling History

The cooldown curve for test no. 7 is given in Graph 1. The rise in the calculated effectiveness to the steady state value is a result of the heat capacity effect of the heat exchanger on the net heat exchange. The heat exchanger effectiveness is the ratio of the actual heat transferred between the ideal maximum as calculated:

$$Effectiveness = (T_{IN} - T_{SW}1)/(T_{IN} - T_{SW}2)$$

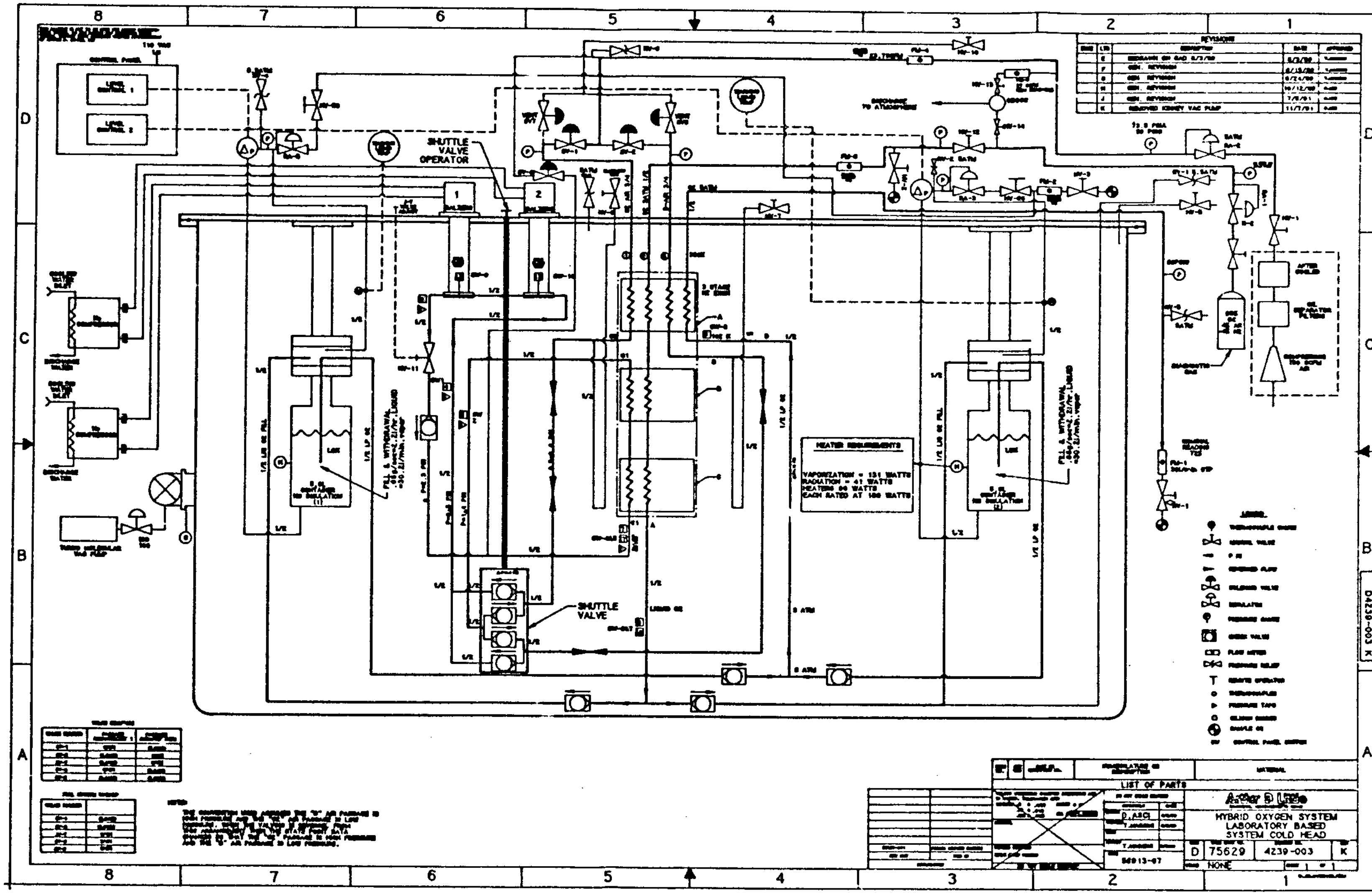


Figure 10. Four-Way Reversing Valve System Schematic.

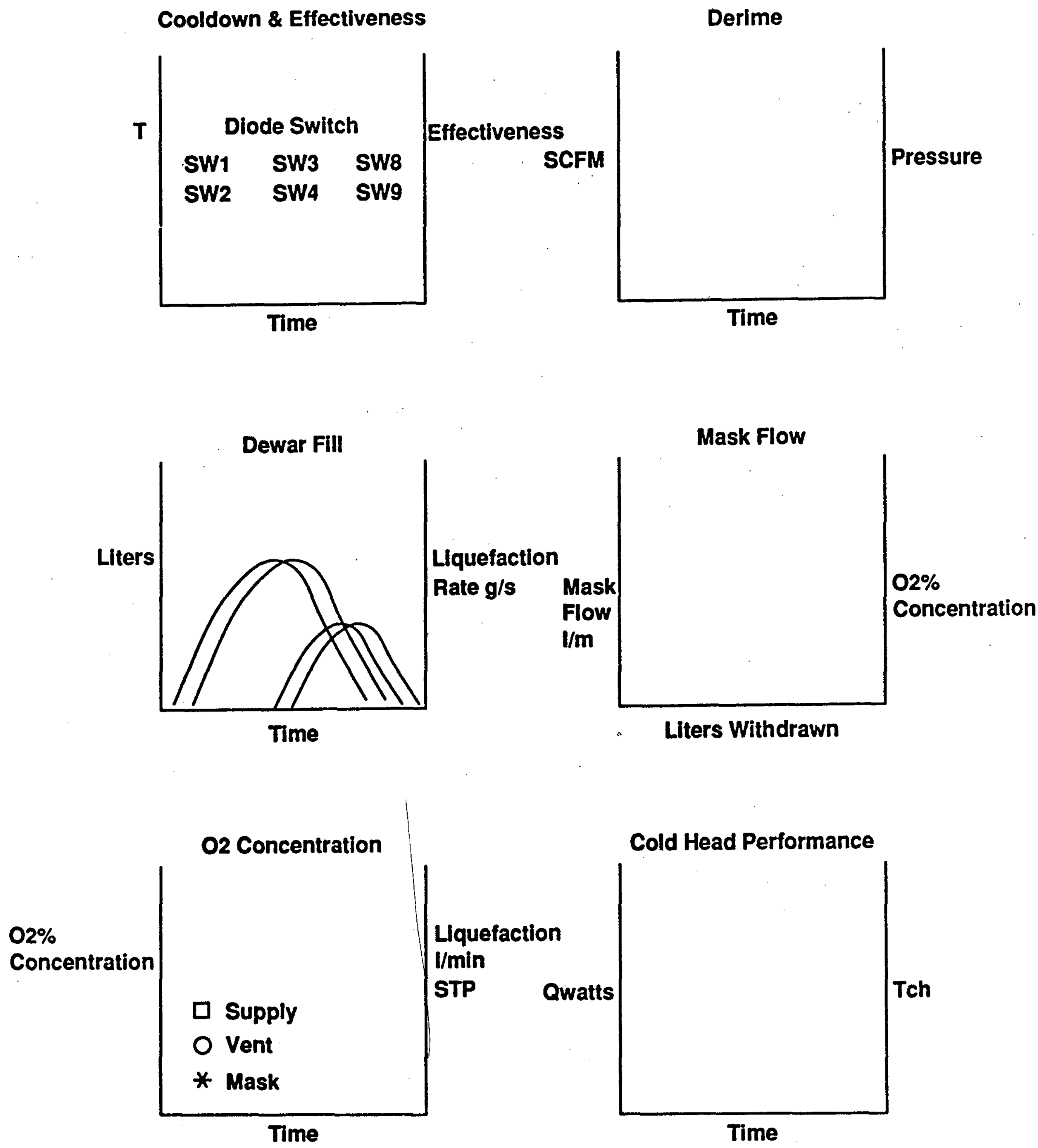
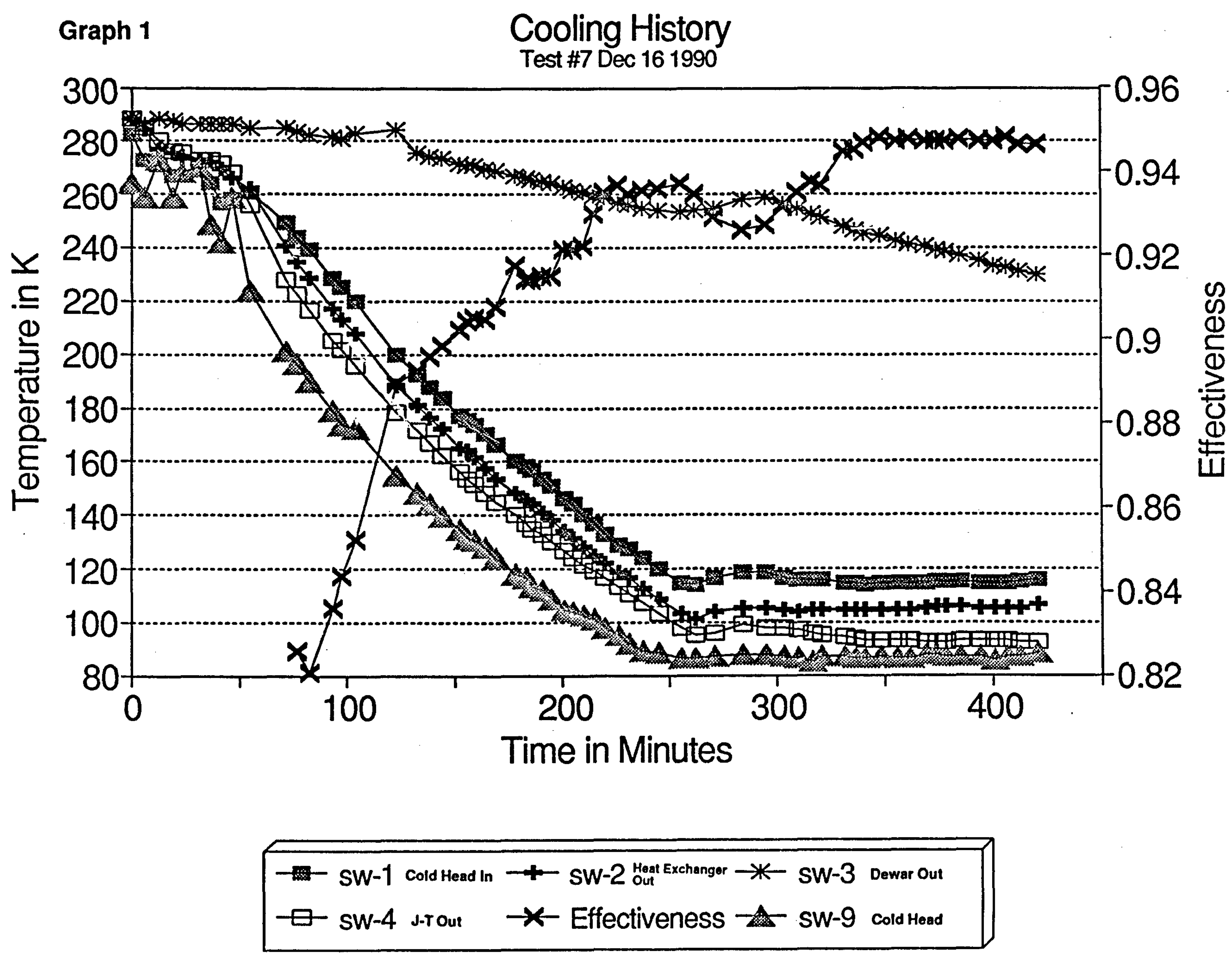


Figure 11. Test Results Format Overview.

Graph 1



Cooling History
Test #7 Dec 16 1990
Temperature in K
Effectiveness
Time in Minutes
300
280
260
240
220
200
180
160
140
120
100
80
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0
100
200
300
400
SW-1 Cold Head In
SW-2 Heat Exchanger Out
SW-3 Dewar Out
SW-4 J-T Out
Effectiveness
SW-9 Cold Head

The design of effectiveness was .968 (excluding conduction heat gain). The measured value was about .95, which is acceptable.

During cooldown all diode temperatures were recorded. The expected cooldown period for the 120 lb heat exchanger, cold head, and other system hardware, was 75 min. The actual cooldown time is given below in Table 21. The increase in cooldown time is due to a loss in cold head refrigeration capacity due to the gradual loss of helium refrigerant as explained later in this section under the *Cold Head Performance* graph.

Table 21. Cooldown Time

	Nov 1989	Dec 13, 1989	Oct 1990	Dec 1990
Cooldown Time Mins.	100	225	225	250

The expected cooldown time for the 4 lb stainless steel flight model heat exchanger (Table 23) would be about 3 minutes.

Graph 2 - Dewar Fill

The amount of LOX produced and the corresponding bleed air flow requirement are essential test parameters.

Rate of Liquefaction = Mass Flow Rate @ FM 6 - Mass Flow Rate @ FM 2

In the oxygen test spreadsheet, the liquefaction rate is time integrated to provide the liquefied volume based upon the flow measurements. The magnehelic pressure gauge also gives cumulative liquid in the dewar, and both of these values are given in the dewar fill graph. The liquefaction rate in grams/second is also shown. There was generally good agreement between the flow measurement and magnehelic measurement of liquid level throughout the test program.

The fluctuation in oxygen flow rate and liquefaction rate seen throughout the test program is intentional operation over the range of capacity to detect system problems.

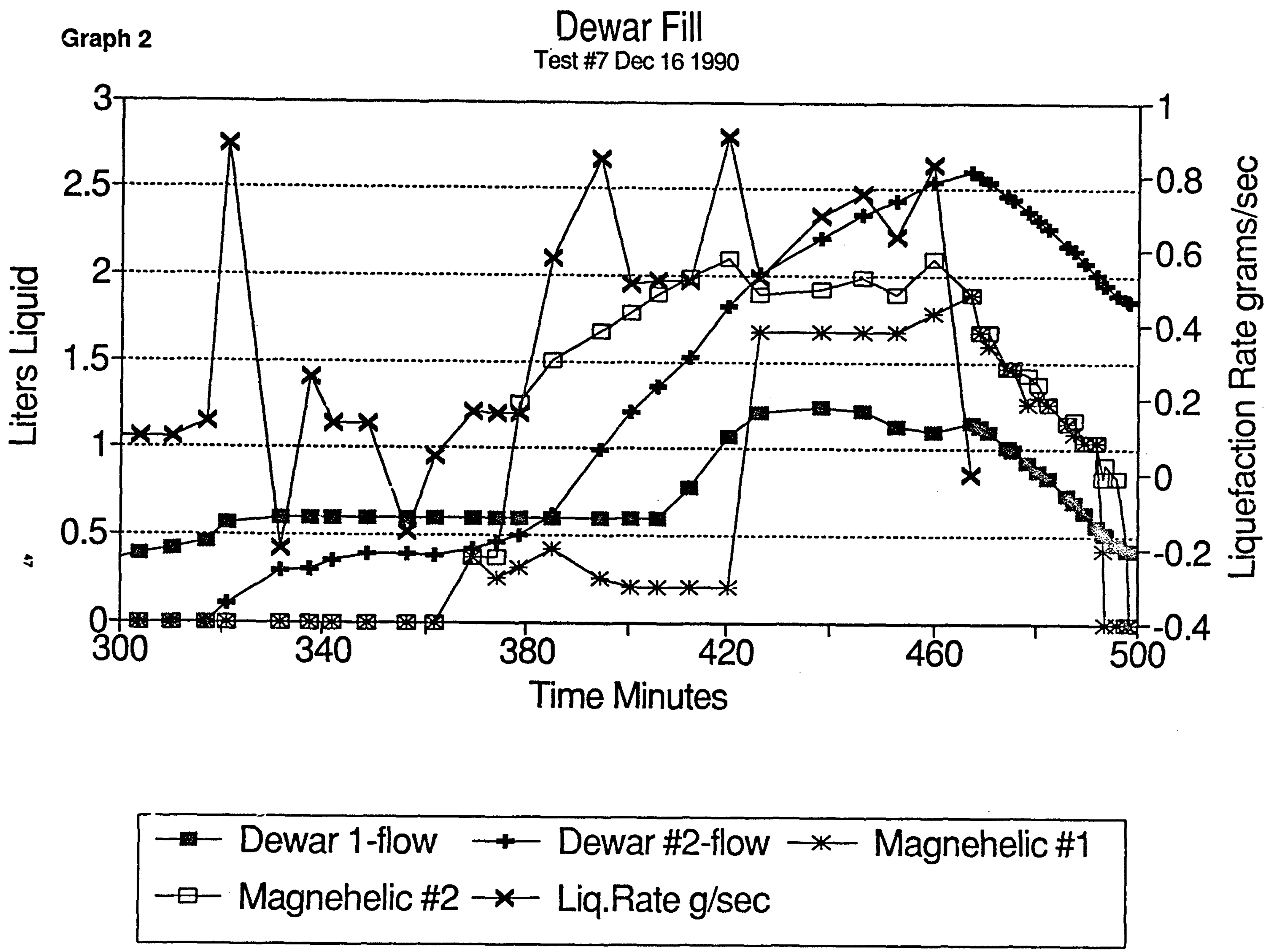
The unit has demonstrated a liquefaction rate of .1 to 1.0 g/sec with a nominal design value of about .5 g/sec in steady state.

We attribute the sudden jump in the magnehelic pressure gage reading seen in this test and others to the dynamic nature of the filling process and the tendency of the magnehelic pressure line to experience vapor-driven surges during the initial stages of dewar filling.

Graph 3 - Heat Exchanger Deriming

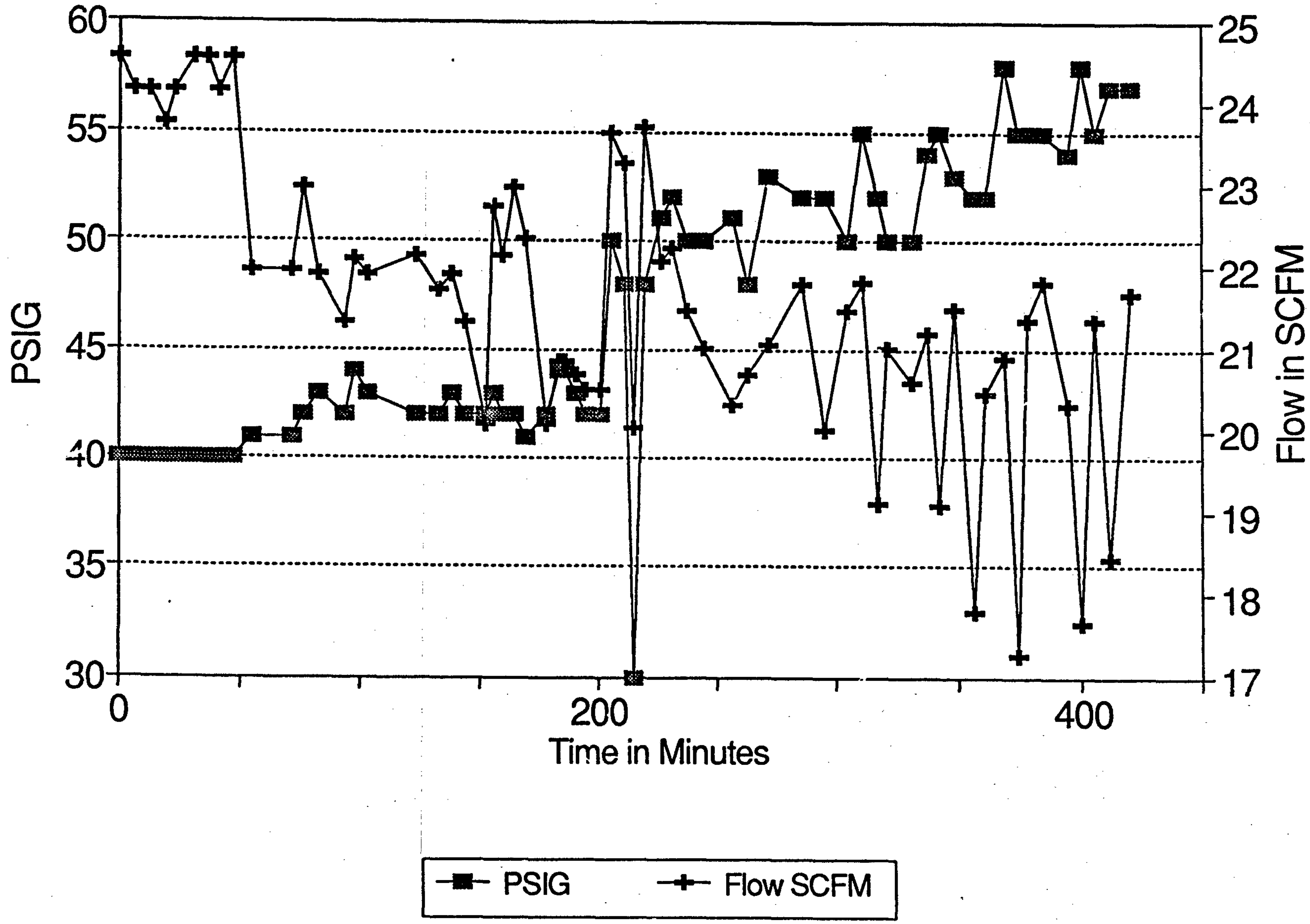
Periodic passage switching to derime the heat exchanger was effective as Graph 3 shows. After liquefaction temperature was achieved (about 200 min), regular deriming was necessary to maintain the flow. As seen in Graph 3, the derime cycle was able to rapidly restore the flow (+) to the design value of about 21 SCFM after falling to 18 or 19 SCFM due to frosting. We are confident of the success of the deriming, particularly, as the supply air was nearly 100% water saturated for all of the tests.

Graph 2


Dewar Fill
Test #7 Dec 16 1990
Liters Liquid
Liquefaction Rate grams/sec
Time Minutes
3
2.5
2
1.5
1
0.5
0
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
300
340
380
420
460
500
Dewar 1-flow
Dewar #2-flow
Magnehelic #1
Magnehelic #2
Liq.Rate g/sec

Graph 3

Heat Exchanger Deriming
Test #7 Dec 16 1990



The unit has demonstrated excellent deriming capability. A 5 min deriming cycle is necessary and adequate during the liquefaction period.

Graph 4 - Mask Oxygen Concentrations

The flow rate of oxygen to the mask from the dewars could be varied from 10 to 55 LPM by adjusting the back pressure regulator. The concentration of oxygen steadily increased as the last batch of oxygen was drawn from the dewar.

The level of concentration is shown to be well in excess of 95% based on measurements from the Beckman oxygen analyzer. This level, we believe, is a consequence of the oxygen separation during the liquefaction phase and batch distillation during the withdrawal phase. The average concentrations of the oxygen in the vent flow were consistently below that of the supply, indicating that separation was taking place. We expect that this phenomena would be observed from any stored LOX supply consisting of an oxygen, nitrogen, and argon mixture.

We suspect that the continuous reading oxygen concentrations are 1% to 3% higher than actual, since the MSOGS supply concentration shown in Graph 5 is 97%, while reliable manufacturers' data and theoretical limits to performance of the MSOGS of this type limit oxygen concentration supply levels to 95.1%.

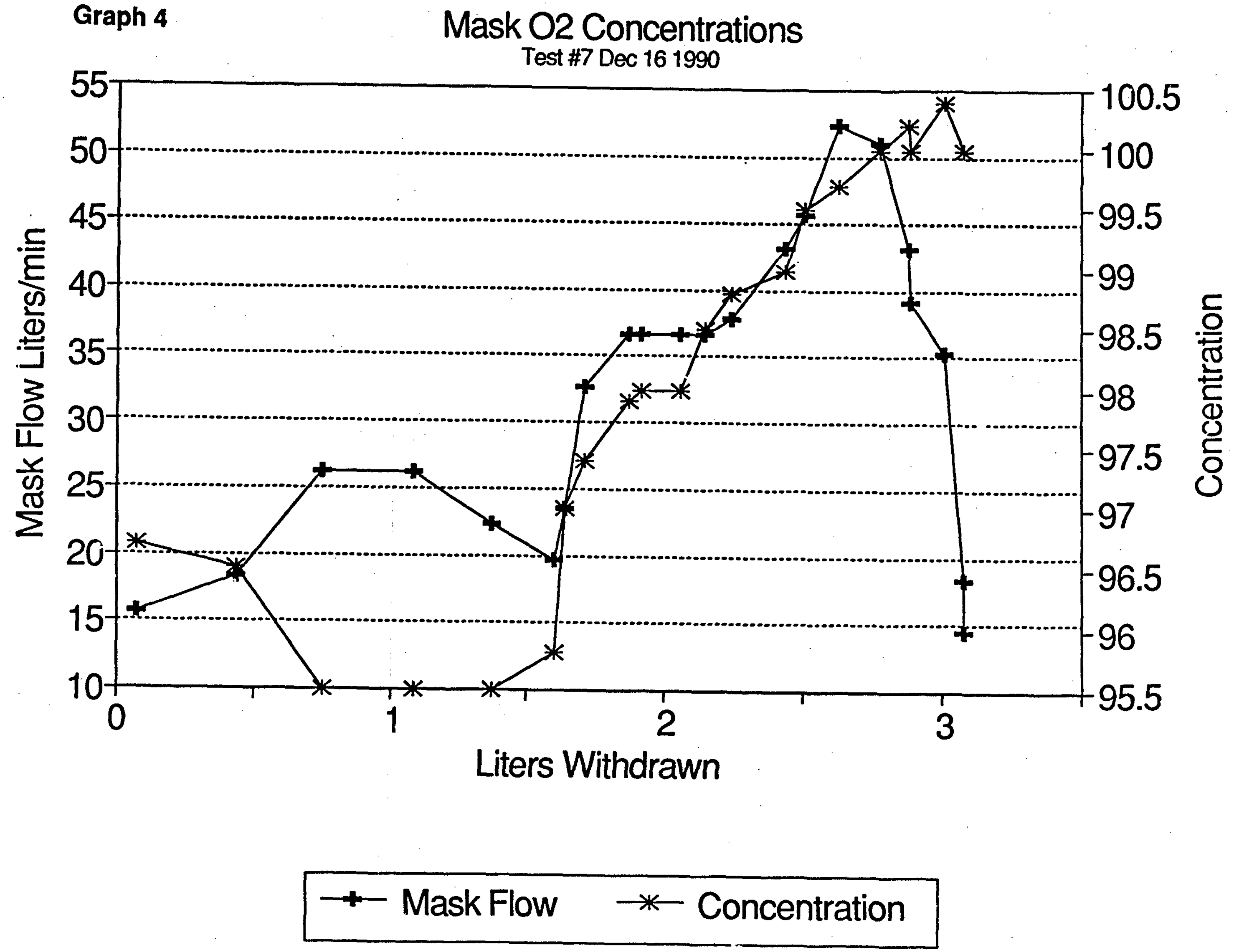
Graph 5 - Oxygen Concentrations

The supply mask and vent concentrations with time are also given in Graph 5. In nearly all of the tests, the vent gas was about 1-2% lower in oxygen concentration than the supply, as we expect that some enrichment of oxygen takes place during liquefaction and filling. A vapor pressure separation occurred during mask liquid withdrawal which raised the oxygen concentration during the later stages of withdrawal, well above the MSOGS supply concentration. We do not know the composition of argon or nitrogen in the vent gas.

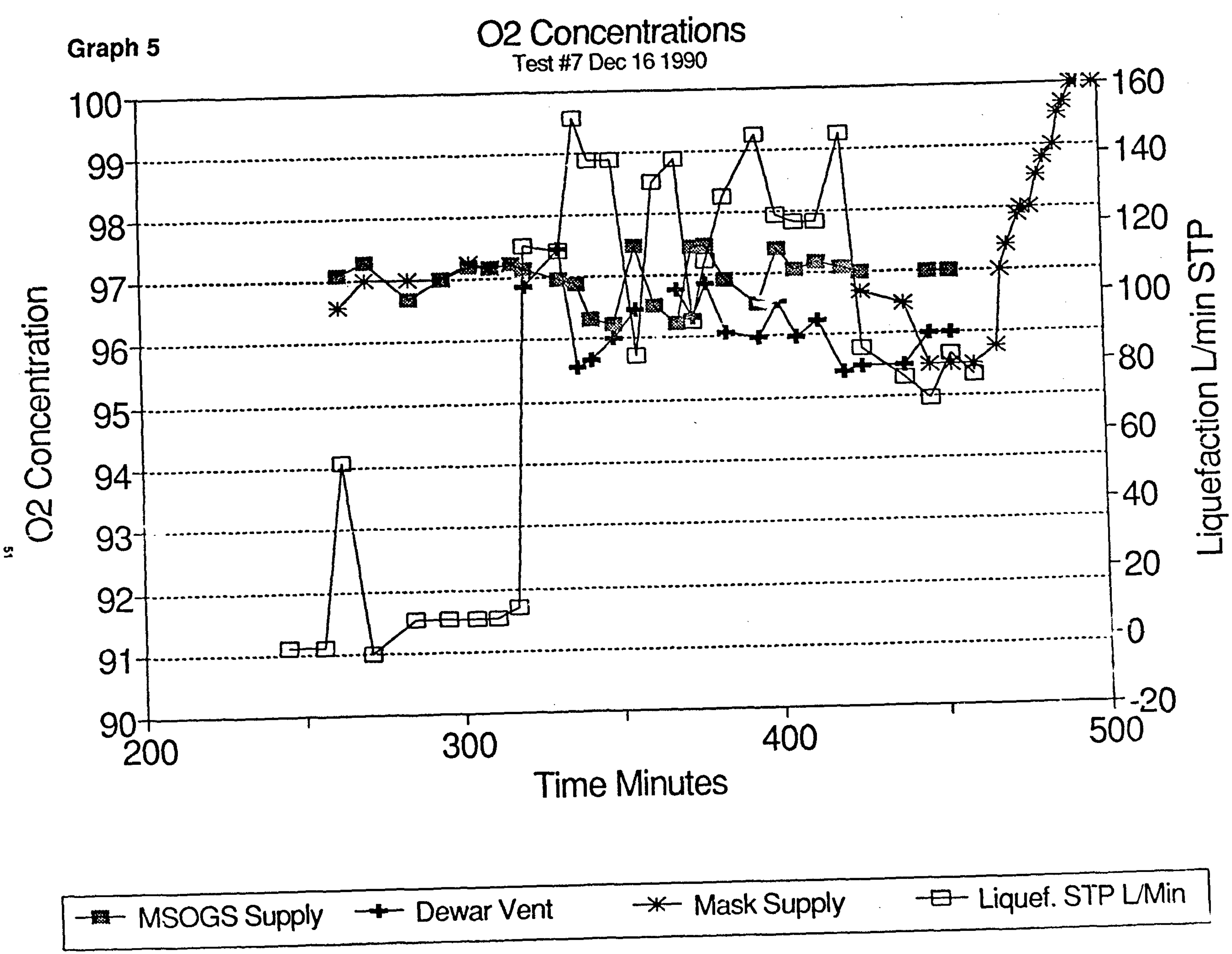
Graph 6 - Cold Head Performance

The predicted and actual cold head cooling performance and corresponding cold head temperature are shown in Graph 6. By oxygen Test No. 7, the cold head cooling capacity is about 50% of the original (and expected value). Loss of the helium charge as a result of connection and reconnection as well as leakage probably account for the loss. Scheduled recharging should be performed.

Graph 4

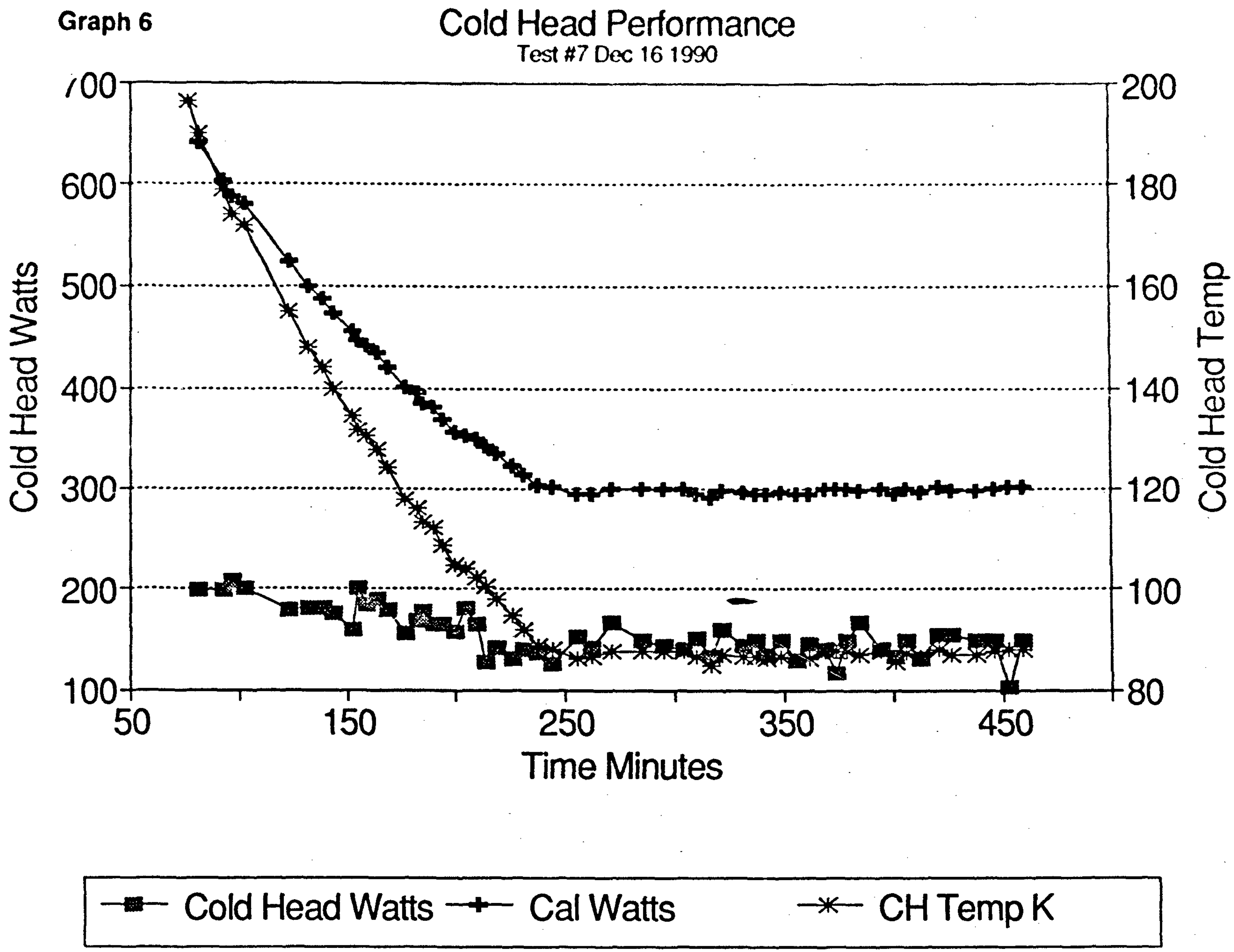

Mask O2 Concentrations
Test #7 Dec 16 1990
Mask Flow Liters/min
55
50
45
40
35
30
25
20
15
10
Concentration
100.5
100
99.5
99
98.5
98
97.5
97
96.5
96
95.5
0
1
2
3
Liters Withdrawn
Mask Flow
Concentration

Graph 5



O2 Concentrations
Test #7 Dec 16 1990
O2 Concentration
100
99
98
97
96
95
94
93
92
91
90
Liquefaction L/min STP
160
140
120
100
80
60
40
20
0
-20
200
300
400
500
Time Minutes
MSOGS Supply
Dewar Vent
Mask Supply
Liquef. STP L/Min

Graph 6



Cold Head Performance
Test #7 Dec 16 1990
Cold Head Watts
700
600
500
400
300
200
100
Cold Head Temp
200
180
160
140
120
100
80
50
150
250
350
450
Time Minutes
Cold Head Watts
Cal Watts
CH Temp K

6. Conclusions and Recommendations

6.1 Conclusions

We have concluded that the open cycle HOS can liquefy and store oxygen from a MSOGS. We are pleased with the excellent performance of the reversing cycle through the initial cooldown (32°F), final cooldown (100°K), and liquefaction run operation (88°K). The HOS laboratory demonstrator has proven that the system can provide refrigeration with dirty (oil and particulates), humid (100% relative humidity) compressed air. We believe that the Air Force should continue the development of the open cycle hybrid system.

6.2 Hybrid Oxygen - Turboexpander Demonstration

We recommend the next step in the open cycle hybrid oxygen program involve the replacement of the cold head and JT valve with a cryogenic expander under concurrent development by the USAF Armstrong Laboratory, Brooks AFB, Texas. The integration of the expander can be accomplished with the existing demonstrator configuration by removing one of the cold heads and replacing it with an appropriately flanged miniature turboexpander.

The procedure for cooldown and operation should not be significantly different than that of the current laboratory demonstrator, except that during the initial cooldown process, a bypass branch around the turbine would be operated so that defrost during initial cooldown can be achieved. After the system has passed through the 20°F point, the standard deriming cycle can be used for the remainder of the cooldown and run.

We recommend that a large flow area exhaust plenum be integrated with the turbine so that it has high frost tolerance even though we were able to achieve cooldown in the cold head demonstrator with a small diameter cold head heat exchanger.

Upon the completion of the test with an integral turbine, we recommend undertaking the design, development and testing with a lightweight cryogenic heat exchanger replacing the commercial aluminum unit currently in the laboratory demonstrator. We expect that a heat exchanger of stainless steel, weighing about 10 lb, would meet the design performance.

6.3 Flight System Design

We further recommend a detailed design and development program of a flight system based on the .5 g/sec liquefier and 2 liters of liquid storage. The major focus of this stage would be to develop a flight-qualified system, including:

- lightweight stainless steel heat exchanger
- integrated liquefier and dewar
- automated controls

<u>Preliminary Flight System</u>

As outlined earlier, the purpose of the laboratory system is to validate the technical feasibility of generating and storing LOX from a bleed air-powered system. The laboratory demonstrator consists of commercially available components and lacks the customization which would be necessary for a flight model. To achieve the size and weight which would be appropriate for a flight system, many of the key components would be different. The most important changes would be the use of the lightweight stainless steel process heat exchanger and the inclusion of a small turboexpander in place of the reciprocating unit.

6.3.1 Flight Heat Exchanger The major characteristics cf the flight heat exchanger is that it would be composed of thin stainless steel plates and fins. The fin plates would reduce the axial conduction which represents an inefficiency in the heat exchanger while thin fin plates enhance the crosswise conductivity, improving the effectiveness of the heat exchanger. The use of thin plates and ultra fins (.001 inch thickness) reduces the size and weight of the heat exchanger for the given duty. Table 22 characterizes the main features of a stainless steel heat exchanger derived from a Garrett design outline in a report entitled, *3.6 K Closed Cycle Turbo-refrigerator*, as compared with the aluminum heat exchanger used in the laboratory test. As indicated earlier, the most important characteristic of this heat exchanger is the thin low axial conductivity metal components used in its fabrication. A more complete description of the stainless heat exchanger is contained in Section 3.2.2, Heat Exchanger, which outlines the characteristics of the interactive component sizing computer program and contains the specifications of the stainless heat exchanger. The key size characteristics of the flight heat exchanger are summarized in Table 23.

Table 22. Comparison of Longitudinal Conduction 2" x 4" Heat Exchanger

Fins	Brazed Aluminum	Stainless
Spacing (fins per inch)	20	40
Number of fins	80	160
Height (inches)	.281	.250
Thickness (inches)	.01	.001
K Btu/hr-ft-R	298	7.1
KA Btu^{-in}/hr-R	5.6	.023
Header Bars Width (inches) K Btu/hr-ft-R KA Btu^{-in}/hr-R	 0.57 298 5.6	 0.50 7.1 .118
Side Plates Thickness K Btu/hr-ft-R KA Btu^{-in}/hr-R	 NA 298 NA	 .02 7.1 .047
Total KA Btu^{-in}/hr-R	11.2	.188

Table 23. Flight Heat Exchanger Size

Core length	7.09 inches
Header length	3.0 inches
Total length	10.0 inches
Volume	2 in. x 5.5 in. or .063 cu ft
Weight	4.6 lbs

6.3.2 Expander Figure 12 shows a schematic of the turboexpander appropriate for operation at the design point of the prototype flight system. The unit is dramatically smaller than the commercially available reciprocating unit, though there are attendant development risks associated with this subsystem which involves the use of an extremely small 500,000 rpm turbine wheel supported by an active gas-bearing system.

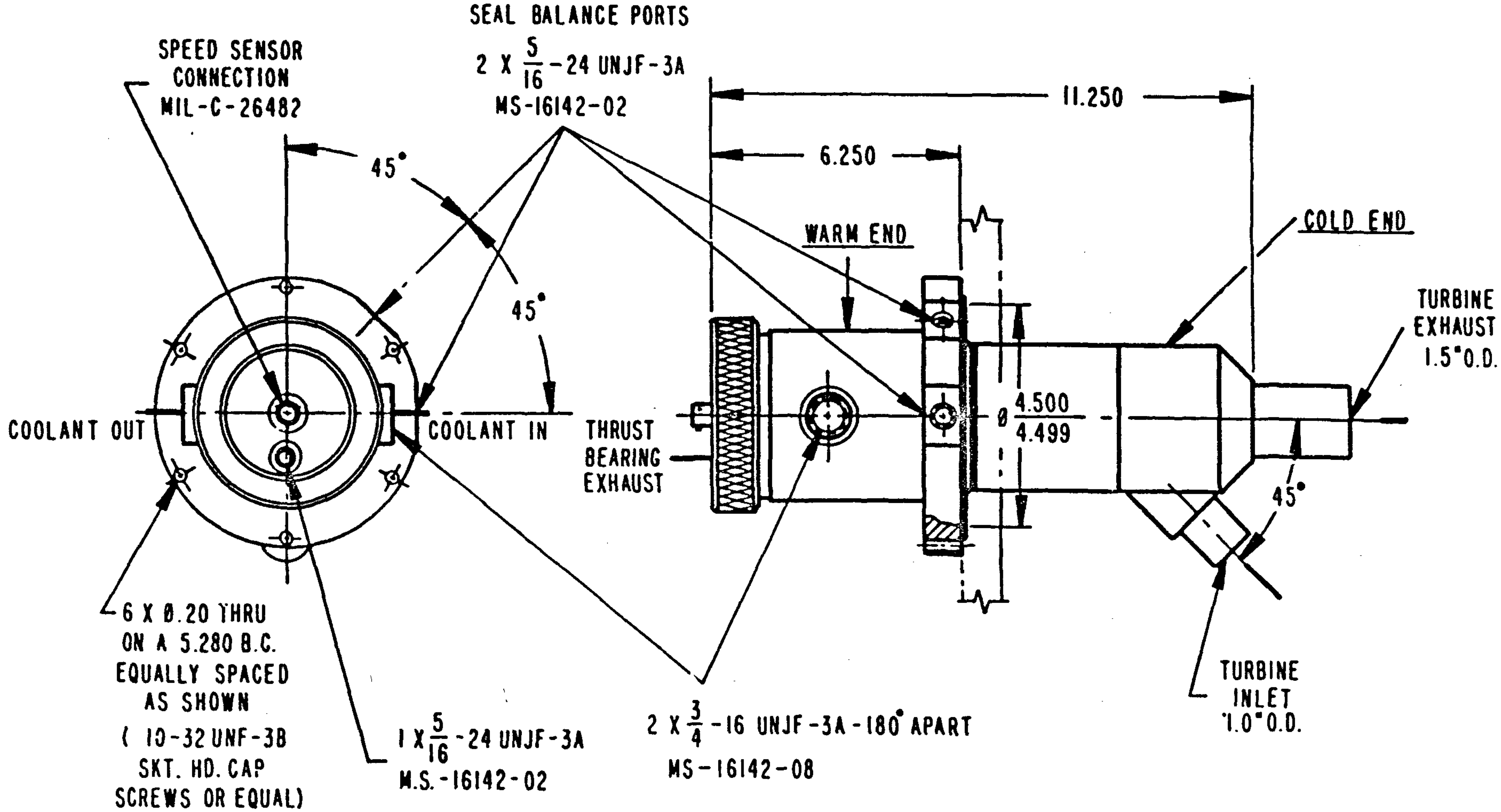


Figure 12. Turboexpander Layout for Aircraft Oxygen Liquefier.

7. Appendixes

7.1 Mission Scenario Specifications

The following tables are contained in the HYBRIDOX.WK1 document and summarize the expected size and weight of a HOS as compared to an MSOGS system without the liquefied storage.

Definition of the Columns on the Tables

Column

1 Altitude - aircraft altitude corresponding to the time in Column 4.

2 MSOGS Output - Essex MSOGS performance data for 94.5% purity MSOGS output in LPM-NTP. See Appendix 7.2 (Boeing Integration Report) for details of these characteristics.

3 0_2 Use Rate - LPM-NTP dilution air or 94.5% oxygen without dilution as indicated.

4 Time - in minutes.

5 Multiplier - activity and crew number multiplier taken from MIL-D-8683B.

6 0_2 - Liters-NTP consumed in each increment. The value at the top of the column is the total 0_2 consumed in the entire mission.

7 MSOGS Output - LPM-NTP of LOX. The figures in the header refer to the liquefier rate and the MSOGS module fraction size 1 - standard size.

8 #1 dewar - the volume of LOX in the first dewar unit.

9 #2 dewar - the volume of LOX in the second dewar unit.

10 % backup - the fraction of mission remaining duration for which there is backup oxygen stored if the MSOGS is not operational. The dewars, MSOGS and liquefier were sized to meet the current demand, and 100% of the mission before 20,000 feet altitude is achieved in the initial climb.

Sizing Assumptions

The standard MSOGS system is assumed to consist of an Essex MSOGS (Figure 9) plus high pressure oxygen bottles of sufficient volume to allow completion of the mission in the event that the MSOGS fails to produce oxygen. Two standard high pressure bottles were chosen in the analysis. Bottles capable of supplying 2,200 liters NTP and 1,200 liters NTP were used throughout the analysis. These bottles weigh 26 and 24 lb, respectively.

The MSOGS unit used in the analysis is based on the 50 LPM-NTP Essex MSOGS unit which weighs 45 lb and is 35 liters in volume. It was assumed that smaller and larger MSOGS units could be provided, varying by size and weight in direct proportion to the rated oxygen capacity in LPM-NTP.

The hybrid unit sizing was developed in the tabular analysis of the mission. The dewar sizing was developed through the analysis of the mission profile assuming two dewars are used and each start with a small residual of LOX left over from the previous mission. The size of the

liquefier is based on the assumption that 2 liters and 10 lb of expander and related plumbing were necessary for a 40 LPM-NTP liquefier. (Later analysis of a stainless steel heat exchanger suggests that the weight would be closer to 4 lb.)

A minimum weight of 15 lb for the total dewar and liquefier for the minimum capacity unit was assumed.

The specific equations used in the spreadsheet analysis, file HYBRIDOX.WK1 follow:

<u>Sizing Relations</u>

Standard MSOGS

I. Volume and weight of backup high pressure oxygen bottle storage

Volume (liters) of backup = 17.99 or 9.48 liter volumes of high pressure gas for 2,200 liters NTP and 1,200 liters NTP high pressure backup bottles, respectively.

Weight (lbs) of backup = 26.04 or 23.9 lb for the 2,200 liters NTP and 1,200 liters NTP cylinders of high pressure gas, respectively.

II. Volume and weight of oxygen concentrator

Volume (liters) of MSOGS units = .7 liters per 1 LPM-NTP of oxygen

Weight (lbs) of MSOGS units = .9 lb per 1 LPM-NTP of oxygen

Based upon the specifications of the Essex Cryogenics 50 LPM concentrator data

III. Total volume and weight of MSOGS system with backup bottles

Total volume = volume backup gas cylinder + volume MSOGS unit

Total weight = weight backup gas cylinder + weight MSOGS units

Hybrid System

I. Volume and weight of liquefier

Volume (liters) of dewar and liquefier = liters dewar #1 + liters dewar #2 + 2.048 (liquefier capacity LPM-NTP/40) + total heat exchanger volume (based on compact heat exchanger design shown on Table 7.1, Preliminary Heat Exchanger Design, from spreadsheet HYBRIDOX.WK1)

Weight (lbs) of dewars and liquefier = 15 + (liquefier capacity LPM-NTP/40) 10 + total heat exchanger weight (based on compact heat exchanger also on HYBRIDOX.WK1)

II. Volume and weight of concentrator

Volume (liters) of MSOGS units = .7 liters per 1 LPM-NTP of oxygen

Weight (lbs) LPM MSOGS unit = .9 lb per 1 LPM-NTP of oxygen

III. Total volume of weight of HOS

Total hybrid volume = volume of dewars + liquefier + MSOGS units

Total hybrid weight = weight of dewars + liquefier + MSOGS units

Table A

MISSION PROFILE
Fighter

% Dewar Remaining previous 75.00%
liquefier 20 LPM-NTP 11.34

Altitude	OBOGS Output LPM-NTP	Dilution O2 Consumed LPM-NTP	Mins	Multi.	Dilution O2 L-NTP Used	OBOG Mult OBOGS #1 Output NTP	0.11 dewar#2 0.75	0.11 dewar 0.75	%Back-up
Mins.to fill					1142				
Ground	0	4.00	0	2.00	0.00	0.00	0.56	0.56	86%
Eng On	40	4.00	15	2.00	120.06	4.46	0.43	0.64	91%
Taxi	40	4.00	20	2.20	44.02	4.46	0.37	0.66	92%
Take-off	40	4.00	30	2.80	112.06	4.46	0.25	0.72	97%
5,000	50	2.50	31	2.60	10.40	5.58	0.25	0.70	97%
10,000	60	2.51	33	2.20	11.00	6.69	0.27	0.69	99%
15,000	70	2.51	35	2.00	10.06	7.81	0.29	0.68	101%
20,000	75	2.51	36	2.00	5.03	8.37	0.30	0.67	102%
25,000	80	2.51	37	2.00	5.03	8.92	0.31	0.67	104%
25,000	80	2.51	38	2.00	5.03	8.92	0.32	0.66	104%
25,000	80	2.51	39	2.00	5.03	8.92	0.33	0.66	105%
25,000	80	2.51	40	2.00	5.03	8.92	0.34	0.65	106%
30,000	90	2.38	41	2.00	5.03	10.04	0.35	0.65	107%
35,000	95	2.33	43	2.00	9.53	10.60	0.37	0.63	110%
40,000	100	2.40	45	2.00	9.34	11.16	0.40	0.62	113%
45,000	110	2.58	[illegible]	2.00	9.60	12.27	0.43	0.61	116%
50,000	120	2.65	49	2.00	10.32	13.39	0.46	0.60	120%
60,000	120	3.23	60	2.00	58.34	13.39	0.62	0.53	143%
60,000	120	3.23	80	3.25	210.21	13.39	0.93	0.29	214%
60,000	120	3.23	105	3.25	262.76	13.39	0.63	0.68	485%
40,000	120	3.23	115	3.25	105.11	13.39	0.51	0.83	901%
20,000	120	3.23	125	2.00	64.68	13.39	0.66	0.76	1908%
1,000	120	3.23	135	2.00	64.68	13.39	0.82	0.68	2015%

	Standard OBOGS Liters	Standard OBOGS weight	Hybrid Liters	Hybrid weight
Backup + Liquefier	17.99	26.04	7.83	29.19
50 LPM OBOGS Units	8.12	10.37	3.23	4.13
	26.11	36.41	11.06	33.32
			57.64%	8.48%
Empty dewar fill time in mins.		216.83		

Table B

MISSION PROFILE
Fighter

% Dewar Remaining previous 75.00%
liquefier 40 LPM-NTP 12.69

Altitude	OBOGS Output LPM-NTP	Dilution O2 Consumed LPM-NTP	Mins	Multi.	95% O2 L-NTP Used 2846	OBOG Mult OBOGS #1 Output NTP	0.36 dewar#2 1.60	0.36 dewar 1.60	%Back-up
Mins.to fill									
Ground	0	4.00	0	2.00	0.00	0.00	1.20	1.20	73%
Eng On	40	4.00	15	2.00	399.00	14.40	0.74	1.45	78%
Taxi	40	4.00	20	2.20	146.30	14.40	0.58	1.53	80%
Take-off	40	4.00	30	2.80	372.40	14.40	0.15	1.69	83%
5,000	50	2.50	31	2.60	28.93	18.00	0.17	1.66	84%
10,000	60	2.51	33	2.20	43.39	21.60	0.22	1.61	86%
15,000	70	2.51	35	2.00	39.45	25.20	0.28	1.57	88%
20,000	75	2.51	36	2.00	19.72	27.00	0.31	1.54	90%
25,000	80	2.51	37	2.00	19.00	28.80	0.34	1.52	93%
25,000	80	2.51	38	2.00	19.00	28.80	0.38	1.50	93%
25,000	80	2.51	39	2.00	19.00	28.80	0.41	1.48	94%
25,000	80	2.51	40	2.00	19.00	28.80	0.44	1.46	96%
30,000	90	2.38	41	2.00	17.01	32.40	0.48	1.44	98%
35,000	95	2.33	43	2.00	31.12	34.20	0.56	1.40	102%
40,000	100	2.40	45	2.00	28.59	36.00	0.64	1.37	106%
45,000	110	2.58	47	2.00	26.06	39.60	0.73	1.34	111%
50,000	120	2.65	49	2.00	24.25	40.00	0.82	1.31	116%
60,000	120	3.23	60	2.00	117.44	40.00	1.32	1.18	147%
60,000	120	3.23	80	3.25	346.98	40.00	0.93	2.09	233%
60,000	120	3.23	105	3.25	433.72	40.00	2.07	1.60	459%
40,000	120	3.23	115	3.25	232.30	40.00	1.60	1.60	601%
20,000	120	3.23	125	2.00	197.24	40.00	1.60	1.60	1047%
1,000	120	3.23	135	2.00	266.00	40.00	1.60	1.60	1047%

	Standard OBOGS Liters	Standard OBOGS weight	Hybrid Liters	Hybrid weight
Backup + Liquefier	27.47	49.94	9.53	33.76
50 LPM OBOGS Units	27.00	34.45	10.44	13.32
	54.47	84.39	19.97	47.08
			63.35%	44.21%
Empty dewar fill time in mins.		143.33		

Table C

			MISSION PROFILE			% Dewar Remaining previous			75.00%
			Fighter		Decompress	liquefier	20 LPM-NTP		11.34
	OBOGS	Dilution			95%	OBOG Mult	0.16	0.16	
Altitude	Output	O2 Consumed			O2 L-NTP	OBOGS #1	dewar#2	dewar	%Back-
	LPM-NTP	LPM-NTP	Mins	Multi.	Used	Output	1.10	1.10	up
Mins.to fill					1692	NTP			
Ground	0	4.00	0	2.00	0.00	0.00	0.83	0.83	85%
Eng On	40	4.00	15	2.00	399.00	6.60	0.37	0.94	88%
Taxi	40	4.00	20	2.20	146.30	6.60	0.20	0.98	89%
Take-off	40	4.00	30	2.80	372.40	6.60	0.28	0.55	93%
5,000	50	2.50	31	2.60	28.93	8.24	0.29	0.52	94%
10,000	60	2.51	33	2.20	40.21	9.89	0.31	0.47	96%
15,000	70	2.51	35	2.00	30.40	11.54	0.34	0.44	99%
20,000	75	2.51	36	2.00	12.67	12.37	0.35	0.42	101%
25,000	80	2.51	37	2.00	10.13	13.19	0.36	0.41	107%
25,000	80	2.51	38	2.00	10.13	13.19	0.38	0.40	105%
25,000	80	2.51	39	2.00	10.13	13.19	0.37	0.41	108%
25,000	80	2.51	40	2.00	10.13	13.19	0.36	0.43	110%
30,000	90	2.38	41	2.00	7.78	14.84	0.37	0.42	112%
35,000	95	2.33	43	2.00	12.30	15.66	0.41	0.41	118%
40,000	100	2.40	45	2.00	9.41	16.49	0.45	0.40	124%
45,000	110	2.58	47	2.00	7.60	18.14	0.49	0.39	130%
50,000	120	2.65	49	2.00	6.51	19.79	0.53	0.38	137%
60,000	120	3.23	60	2.00	15.92	19.79	0.52	0.63	177%
60,000	120	3.23	80	3.25	47.05	19.79	0.46	1.08	260%
60,000	120	3.23	105	3.25	58.81	19.79	1.03	1.01	389%
40,000	120	3.23	115	3.25	76.45	19.79	0.94	1.24	497%
20,000	120	3.23	125	2.00	126.67	19.79	1.17	1.09	776%
1,000	120	3.23	135	2.00	253.33	19.79	0.88	1.32	754%

	Standard OBOGS		Hybrid	
	Liters	weight	Liters	weight
Backup + Liquefier	17.99	26.04	8.53	30.52
50 LPM OBOGS Units	27.00	34.45	4.78	6.10
	44.99	60.49	13.31	36.62
			70.42%	39.46%
Empty dewar fill time in mins.		215.14		

Table D

			MISSION PROFILE			% Dewar Remaining previous			1.00%
			Fighter		Decompressliquefier			30 LPM-NTP	10.79
	OBOGS	Dilution			95%	OBOG Mult	0.35	0.20	
Altitude	Output	O2 Consumed			O2 L-NTP	OBOGS #1	dewar#2	dewar	%Back-
	LPM-NTP	LPM-NTP	Mins	Multi.	Used	Output	1.10	1.10	up
Mins.to fill					775	NTP			
Ground	0	4.00	0	2.00	0.00	0.00	0.01	0.01	2%
Eng On	40	4.00	15	2.00	0.00	14.00	0.25	0.01	29%
Taxi	40	4.00	20	2.20	0.00	14.00	0.33	0.01	38%
Take-off	40	4.00	30	2.80	0.00	14.00	0.49	0.01	56%
5,000	50	2.50	31	2.60	28.93	17.50	0.51	-0.02	57%
10,000	60	2.51	33	2.20	40.21	21.00	0.47	0.03	61%
15,000	70	2.51	35	2.00	30.40	24.50	0.52	-0.01	66%
20,000	75	2.51	36	2.00	12.67	26.25	0.55	-0.02	69%
25,000	80	2.51	37	2.00	10.13	28.00	0.58	-0.03	75%
25,000	80	2.51	38	2.00	10.13	28.00	0.62	-0.05	77%
25,000	80	2.51	39	2.00	10.13	28.00	0.60	-0.01	81%
25,000	80	2.51	40	2.00	10.13	28.00	0.59	0.02	85%
30,000	90	2.38	41	2.00	7.78	30.00	0.63	0.01	90%
35,000	95	2.33	43	2.00	12.30	30.00	0.69	-0.01	100%
40,000	100	2.40	45	2.00	9.41	30.00	0.76	-0.02	110%
45,000	110	2.58	47	2.00	7.60	30.00	0.83	-0.02	120%
50,000	120	2.65	49	2.00	6.51	30.00	0.90	-0.03	131%
60,000	120	3.23	60	2.00	15.92	30.00	0.88	0.34	190%
60,000	120	3.23	80	3.25	47.05	30.00	0.83	1.03	314%
60,000	120	3.23	105	3.25	58.81	30.00	1.69	0.96	505%
40,000	120	3.23	115	3.25	76.45	30.00	1.60	1.31	665%
20,000	120	3.23	125	2.00	126.67	30.00	1.94	1.16	1065%
1,000	120	3.23	135	2.00	253.33	30.00	1.65	1.50	1084%

	Standard OBOGS		Hybrid	
	Liters	weight	Liters	weight
Backup + Liquefier	17.99	26.04	5.93	25.85
50 LPM OBOGS Units	16.78	21.41	10.15	12.95
	34.77	47.45	16.08	38.80
			53.76%	18.24%

Table E

MISSION PROFILE
B1-Bomber

% Dewar Remaining previous 75.00%
liquefier 40 LPM-NTP 12.69

	OBOGS	Dilution			Dilution	OBOG Mult	0.28	0.28	
Altitude	Output	O2 Consumed			O2 L-NTP	OBOGS #1	dewar#2	dewar	%Back-
	LPM-NTP	LPM-NTP	Mins	Multi.	Used	Output	6.00	6.00	up
Mins.to fill					9083	NTP			
Ground	0	4.00	8	6	638.40	0.00	4.50	4.50	93%
Eng On	40	4.00	15	6	168.08	11.10	4.31	4.59	94%
Taxi	40	4.00	20	6	120.06	11.10	4.17	4.65	94%
Take-off	40	4.00	30	8	324.16	11.10	3.80	4.78	95%
5,000	50	2.50	31	7	28.00	13.88	3.82	4.75	95%
10,000	60	2.51	33	6	30.00	16.65	3.85	4.71	96%
15,000	70	2.51	35	6	30.17	19.43	3.90	4.68	96%
20,000	75	2.51	37	6	30.17	20.82	3.95	4.64	97%
25,000	80	2.51	100	6	950.29	22.20	5.54	3.56	151%
25,000	80	2.51	150	6	754.20	22.20	4.68	4.83	138%
25,000	80	2.51	200	6	754.20	22.20	3.82	6.10	164%
25,000	80	2.51	250	6	754.20	22.20	2.96	7.36	200%
25,000	80	2.51	300	6	754.20	22.20	4.23	6.50	249%
30,000	90	2.38	340	6	603.36	24.98	5.37	5.81	309%
35,000	95	2.33	350	6	142.92	26.37	5.67	5.65	328%
40,000	100	2.40	360	7	163.38	27.75	5.99	5.46	351%
45,000	110	2.58	380	8	384.00	30.53	6.69	5.02	415%
50,000	120	2.65	440	11	1625.40	33.31	4.83	7.31	1275%
60,000	120	3.23	441	0	0.00	33.31	4.87	7.31	1279%
60,000	120	3.23	442	0	0.00	33.31	4.90	7.31	1283%
60,000	120	3.23	443	0	0.00	33.31	4.94	7.31	1287%
40,000	120	3.23	450	8	181.10	33.31	5.21	7.10	1656%
20,000	120	3.23	460	8	258.72	33.31	5.59	6.80	2779%
1,000	120	3.23	480	6	388.08	33.31	6.35	6.36	2850%

	Standard OBOGS		Hybrid	
	Liters	weight	Liters	weight
Backup + Liquefier	81.46	128.06	18.33	63.83
50 LPM OBOGS Units	23.50	29.98	8.05	10.27
	104.96	158.04	26.38	74.10
			74.87%	53.11%

Empty dewar fill time in mins. 697.18

Table F

MISSION PROFILE
B1-Bomber

% Dewar Remaining previous 75.00%
liquefier 100 LPM-NTP 36.72
OBOG Mult 0.83 0.83

Altitude	OBOGS Output LPM-NTP	Dilution O2 Consumed LPM-NTP	Mins	Multi.	95% O2 L-NTP Used 28752	OBOGS Output NTP	#1 dewar 14.00	#2 dewr 14.00	%Back-up
Mins.to fill									
Ground	0	4.00	8	6	638.40	0.00	10.50	10.50	65%
Eng On	40	4.00	15	6	558.60	33.08	9.86	10.76	65%
Taxi	40	4.00	20	6	399.00	33.08	9.41	10.95	65%
Take-off	40	4.00	30	8	1077.30	33.08	8.17	11.33	65%
5,000	50	2.50	31	7	77.90	41.35	8.22	11.24	65%
10,000	60	2.51	33	6	118.34	49.62	8.34	11.11	65%
15,000	70	2.51	35	6	118.34	57.89	8.47	10.97	66%
20,000	75	2.51	37	6	118.34	62.03	8.61	10.84	66%
25,000	80	2.51	100	6	3591.00	66.16	13.37	6.73	107%
25,000	80	2.51	150	6	2850.00	66.16	10.12	10.51	93%
25,000	80	2.51	200	6	2850.00	66.16	6.86	14.29	11[illegible]%
25,000	80	2.51	250	6	2850.00	66.16	3.60	18.07	140%
25,000	80	2.51	300	6	2850.00	66.16	7.38	14.82	181%
30,000	90	2.38	340	6	2041.14	74.43	10.78	12.48	235%
35,000	95	2.33	350	6	466.86	78.57	11.68	11.95	252%
40,000	100	2.40	360	7	500.33	82.70	12.63	11.38	273%
45,000	110	2.58	380	8	1042.29	90.97	14.71	10.19	328%
50,000	120	2.65	440	11	3819.00	99.24	10.34	16.99	854%
60,000	120	3.23	441	0	0.00	99.24	10.46	16.99	857%
60,000	120	3.23	442	0	0.00	99.24	10.57	16.99	861%
60,000	120	3.23	443	0	0.00	99.24	10.68	16.99	865%
40,000	120	3.23	450	8	400.27	99.24	11.48	16.54	1022%
20,000	120	3.23	460	8	788.95	99.24	12.61	15.63	1540%
1,000	120	3.23	480	6	1596.00	99.24	14.88	13.81	1564%

	Standard OBOGS Liters	Standard OBOGS weight	Hybrid Liters	Hybrid weight
Backup + Liquefier	225.41	336.38	38.42	132.89
50 LPM OBOGS Units	78.10	99.65	23.98	30.60
	303.51	436.03	62.41	163.49
			79.44%	62.50%

Empty dewar fill time in mins. 543.94

			MISSION PROFILE			% Dewar Remaining previous			75.00%
			B1-Bomber		Decompress	liquefier	80	LPM-NTP	25.37
	OBOGS	Dilution			95%	OBOG Mult	0.49	0.49	
Altitude	Output	O2 Consumed			O2 L-NTP	OBOGS	#1 dewar	#2 dewar	%Back-
	LPM-NTP	LPM-NTP	Mins	Multi.	Used	Output	11.00	11.00	up
Mins.to fill					15795	NTP			
Ground	0	4.00	8	6	638.40	0.00	8.25	8.25	95%
Eng On	40	4.00	15	6	558.60	19.54	7.61	8.41	95%
Taxi	40	4.00	20	6	399.00	19.54	7.16	8.52	96%
Take-off	40	4.00	30	8	1077.30	19.54	5.92	8.74	97%
5,000	50	2.50	31	7	77.90	24.42	5.95	8.65	97%
10,000	60	2.51	33	6	109.66	29.31	6.02	8.53	98%
15,000	70	2.51	35	6	91.20	34.19	6.10	8.42	98%
20,000	75	2.51	37	6	76.00	36.64	6.18	8.34	99%
25,000	80	2.51	100	6	1915.20	39.08	8.99	6.15	169%
25,000	80	2.51	150	6	1520.00	39.08	11.23	4.41	146%
25,000	80	2.51	200	6	1520.00	39.08	9.49	6.64	180%
25,000	80	2.51	250	6	1520.00	39.08	7.75	8.88	230%
25,000	80	2.51	300	6	1520.00	39.08	6.02	11.11	312%
30,000	90	2.38	340	6	933.71	43.96	8.03	10.04	410%
35,000	95	2.33	350	6	184.57	46.41	8.56	9.83	438%
40,000	100	2.40	360	7	164.67	48.85	9.11	9.64	468%
45,000	110	2.58	380	8	304.00	53.73	10.34	9.30	537%
50,000	120	2.65	440	11	1026.00	58.62	14.36	8.12	906%
60,000	120	3.23	441	0	0.00	58.62	14.36	8.12	906%
60,000	120	3.23	442	0	0.00	58.62	14.36	8.12	906%
60,000	120	3.23	443	0	0.00	58.62	14.36	8.12	906%
40,000	120	3.23	450	8	131.73	58.62	14.21	8.59	979%
20,000	120	3.23	460	8	506.67	58.62	13.63	9.26	1310%
1,000	120	3.23	480	6	1520.00	58.62	11.90	10.60	1288%

	Standard OBOGS		Hybrid	
	Liters	weight	Liters	weight
Backup + Liquefier	117.44	180.14	30.37	104.29
50 LPM OBOGS Units	78.10	99.65	14.17	18.07
	195.55	279.79	44.54	122.37
			77.22%	56.27%
Empty dewar fill time in mins.		726.23		

Table H

MISSION PROFILE
B1-Bomber

% Dewar Remaining previous 1.00%
Decompressliquefier 80 LPM-NTP 22.11
95% OBOG Mult 0.76 0.76

Altitude	OBOGS Output LPM-NTP	Dilution O2 Consumed LPM-NTP	Mins	Multi.	O2 L-NTP Used	OBOGS Output NTP	#1 dewar 11.00	#2 dewar 11.00	%Back-up
Mins.to fill					13121				
Ground	0	4.00	8	6	0.00	0.00	0.11	0.11	1%
Eng On	40	4.00	15	6	0.00	30.45	0.11	0.11	1%
Taxi	40	4.00	20	6	0.00	30.45	0.28	0.11	3%
Take-off	40	4.00	30	8	0.00	30.45	0.63	0.11	5%
5,000	50	2.50	31	7	77.90	38.06	0.68	0.02	5%
10,000	60	2.51	33	6	109.66	45.67	0.55	0.13	5%
15,000	70	2.51	35	6	91.20	53.28	0.67	0.02	5%
20,000	75	2.51	37	6	76.00	57.09	0.80	-0.07	5%
25,000	80	2.51	100	6	1915.20	60.90	-1.39	4.32	33%
25,000	80	2.51	150	6	1520.00	60.90	2.09	2.58	44%
25,000	80	2.51	200	6	1520.00	60.90	0.36	6.06	71%
25,000	80	2.51	250	6	1520.00	60.90	3.84	4.32	113%
25,000	80	2.51	300	6	1520.00	60.90	2.10	7.80	181%
30,000	90	2.38	340	6	933.71	68.51	5.23	6.74	271%
35,000	95	2.33	350	6	184.57	72.32	6.06	6.53	300%
40,000	100	2.40	360	7	164.67	76.12	6.93	6.34	331%
45,000	110	2.58	380	8	304.00	80.00	8.76	5.99	403%
50,000	120	2.65	440	11	1026.00	80.00	14.24	4.82	768%
60,000	120	3.23	441	0	0.00	80.00	14.24	4.82	768%
60,000	120	3.23	442	0	0.00	80.00	14.24	4.82	768%
60,000	120	3.23	443	0	0.00	80.00	14.33	4.82	772%
40,000	120	3.23	450	8	131.73	80.00	14.18	5.46	843%
20,000	120	3.23	460	8	506.67	80.00	15.10	4.88	1143%
1,000	120	3.23	480	6	1520.00	80.00	13.36	6.71	1149%

	Standard OBOGS Liters	Standard OBOGS weight	Hybrid Liters	Hybrid weight
Backup + Liquefier	99.45	154.10	27.77	57.94
50 LPM OBOGS Units	45.18	57.65	22.08	28.16
	144.63	211.75	49.85	86.11
			65.53%	59.34%
Empty dewar fill time in mins.		6.21		

7.2 Boeing Integration Report

L-7170-AKT-87-046

HYBRID OXYGEN SYSTEM
PHASE I SUPPORT

TECHNICAL REPORT

REVISION A

Submitted to:

Arthur D. Little, Inc.
Acorn Park
Cambridge, Massachusetts 02140

November 25, 1987

Submitted by:

The Boeing Advanced Systems Company
A Division of The Boeing Company
Seattle, Washington 98124

Prepared by:

Coral A. Bernier
Principal Investigator

Approved by:

Arun K. Trikha
Program Manager

FOREWORD

Revision A to the Technical Report is a major revision to the original report submitted in August 1987. It includes:

(1) Updated bleed air analysis based on A. D. Little's configuration change reflected in the May 1987 version of the Phase I Report (Reference 1).

(2) Appendix 1 containing detailed analysis of Hybrid Oxygen System retrofit in the F-15 aircraft.

(3) Appendix 2 providing the methodology and resources to calculate partial pressures of atmospheric constituents as a function of geometric altitude.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 SUMMARY/INTRODUCTION

This report was prepared by the Boeing Advanced Systems Company to summarize the work conducted in support of Arthur D. Little, Inc. (ADL) on the Hybrid Oxygen System (HOS) program. This report contains information on availability of bleed air for the HOS in typical fighter and bomber aircraft, discussions on system integration and feasibility, and identification of potential use and function of the additional cooling capability inherent in the HOS design.

The HOS discussed herein is based on the system as described in ADL's Phase I Report (Reference 1). The HOS consists of an onboard oxygen liquifier which processes the concentrated oxygen from the onboard oxygen generation system (OBOGS) and stores it as liquid (see Figures 5 and 6 of Reference 1). Bleed air is required for two functions in the hybrid system:

1. Liquid oxygen generation, and
2. Heat sink for oxygen liquefaction.

Requirements for the bleed air supply for oxygen concentrating through the OBOGS are established based on oxygen breathing volume requirements. The design flow of oxygen from the OBOGS in the HOS is set at 40 LPM (NTP). The required bleed air flow for liquifaction is a function of the OBOGS output, the temperature of the heat sink bleed air at the exit of the liquifier heat exchanger, and the heat removal required for oxygen liquifaction.

2.0 INTEGRATION ISSUES

Based on the liquifier design trade studies conducted by ADL, it was determined that the amount of bleed air required for system operation ranged from 1.2 to 1.9 lbm/min. The variation in flow rate is related to the selected design condition at the exit of the liquefier heat exchanger. An OBOGS unit was recently flight tested as part of the Tactical Life Support System demonstration (Reference 2) on an F-15 aircraft. This unit required a flow rate of 2 lbm/min and its installation in the F-15 and consequent flow extraction proved to have minimal effect on the aircraft environmental control system (ECS). This fact was verified by computer

simulation and evaluation of flight test data. It is therefore believed that retrofit installation of the Hybrid Oxygen System in the F-15 and other aircraft will render no adverse effects either on the operation of the aircraft ECS or on aircraft performance. The HOS, with its low weight and volume characteristics, provides an excellent alternative to onboard stored oxygen. This system, because it produces oxygen at conventional pressure, will be compatible with either the CRU-73 or BRAG regulator. Appendix 1 examines the F-15 retrofit installation of the HOS in detail.

3.0 BLEED AIR AVAILABILITY

The quantity and thermodynamic state of the ECS bleed air supply is given in Tables 1 and 2 for generic fighter and bomber missions, respectively. These conditions, as well as ECS bleed air location, were chosen based on design specification values for a typical (NGL) OBOGS unit (i.e., 25 to 90 psig, required performance from 0°F to 100°F, operating to 160°F). The conditions from the fighter mission (Table 1) most closely matching the required OBOGS conditions are at the exit of the secondary heat exchanger. A heat exchanger may be necessary prior to OBOGS in the case of the bomber mission.

4.0 EXCESS COOLING POTENTIAL

Depending on the design and baseline operating state of the HOS, a range of options exist for generating excess cooling potential. For instance, the bleed air stream at the exit of the liquefier section, disregarding the low pressure, has excellent cooling potential. Also, the liquid oxygen after extraction from the dewar could be used as a heat sink prior to delivery to mask. Analysis of the HOS performance as well as overall aircraft ECS performance would have to be done to determine the worth or advantage of external use of excess cooling from the HOS. In order to determine where to tap off of the HOS for additional cooling the following questions must be answered or trades conducted:

1. What are the payoffs and/or weight penalties associated with increased cooling capability at the expense of increased sizing in heat exchangers or turboexpander?

2. What are the payoffs and/or weight penalties associated with increased cooling capability achieved through increased OBOGS output?

Additional cooling is necessary in present day and future electronics exhibiting high power density. Specific needs include cooling for avionics, advanced sensors, and applications for VHSIC (very high speed integrated circuit) and VLSIC (very large scale integrated circuits). The HOS could also be designed to use the vent bleed air as a bootstrap to precool the inlet bleed air. Use of the hybrid system as a bleed air conditioner and additional details on specific application of the excess cooling potential is found in Appendix 1.

5.0 CONCLUSIONS

The HOS being developed by A. D. Little, by processing the concentrated oxygen from the OBOGS and storing it as a liquid, preserves the conventional reliability and convenience of stored onboard oxygen while reducing the logistics burden of stored onboard liquid oxygen (LOX). The HOS, with its minimal bleed air requirements, can be used as a retrofit solution to LOX in current aircraft and as an alternative solution to LOX in future aircraft. The hybrid system also provides an excellent source of clean conditioned bleed air and inherently possesses potential for use in aircraft/avionics cooling.

TABLE 1: FIGHTER MISSION BLEED AIR AVAILABILITY

CONDITION	ALTITUDE 1000 Ft.	MACH No.	Single Primary HX POUT psia	Single Primary HX TOUT °F	Single Primary HX W lb/min	Secondary HX POUT psia	Secondary HX TOUT °F	Secondary HX W lb/min
Taxi	0	0	43	245	55	67	143	73
T/O	0	0.3	76	276	55	75	120	83
Climb	35	0.85	38	492	39	56	130	63
Supersonic Climb & Cruise	60	2.0	62	505	45	85	320	84
Descent	30	0.56	29	212	42	37	22	44

NOTES: Hot day condition
Fighter Mission
Air Cycle ECS

L-7170-AKT-87-046

TABLE 2: BOMBER MISSION BLEED AIR AVAILABILITY

			Precooler Outlet			Primary HX Outlet		
Design Condition	ALTITUDE 1000 Ft.	MACH No.	Pphx psia	Tphx OF	Wphx lb/min	Phx psia	Thx OF	Whx lb/min
Taxi	0	0	88	250	125	77	195	123.5
T/O	0	0	131	234	126	77	187	124.5
LO Cruise	27	.81	73	210	121	39	164	120
HI Cruise	47	.81	29	222	111	28	136	104
Descent	47	.81	24	282	77	23	166	70
Landing	0	.26	105	175	77	48	142	76

NOTES: Hot Day Condition.
Bomber Mission
Air Cycle ECS

APPENDIX 1: F-15 RETROFIT ANALYSIS

This appendix presents design integration issues and identifies the advantages of retrofit of the Hybrid Oxygen System (HOS) into the F-15 aircraft. The F-15 is only used as an example to illustrate the methodology required for retrofit analysis and to specify the potential worth of the HOS both as an air purification system and as a valuable source for air for avionics cooling. In this day and age when the threat of chemical, biological, and radiological (CBR) warfare is very real, any system offering inherent protection should be seriously evaluated. Contained within this appendix are the following specific items:

(1) Retrofit of the HOS in the F-15
(2) Use of the Conditioned Bleed Air
(3) Use of Excess Cooling Potential

F-15 Retrofit of the Hybrid Oxygen System

The F-15 is a single-place supersonic fighter aircraft powered by two engines. The F-15 environmental control system (ECS) provides conditioned air to the cockpit for heating, cooling, pressurization, and ventilation; to the aircraft avionic compartments requiring environmental temperature control; and to those equipment units requiring direct forced air cooling. In addition, conditioned air is provided for windshield anti-icing and anti-fogging and for pressurization of the cockpit canopy seal, fuel tanks, anti-G suits and that avionic equipment requiring pressurization.

A schematic of the F-15 bleed air and environmental control system is given in Figure 1-1. A detailed description of the system and of each of the subsystems/components of the F-15 ECS may be found in References (3) and (4). Bleed air in the F-15 is obtained from the final compressor stage bleed port of each engine. The bleed control system is duplicated for each engine and consists of a primary bleed air pressure regulator/shutoff valve (75 ± 15 psig), a secondary bleed air pressure regulator/shutoff valve (120 ± 20 psig), a primary heat exchanger, an ejector, a primary heat exchanger bypass modulating valve, a preconditioned bleed air temperature sensor, and a preconditioned bleed air overtemperature sensor. The regulated bleed air passes through the primary heat exchange and is reduced to near ram air temperatures.

The F-15 was evaluated to determine the most appropriate location for retrofit of the HOS. Guidelines used for this determination were design specifications for an onboard oxygen generating system (OBOGS): pressure of from 25 to 90 psig and temperature of from 40° to 90°F.* These requirements are based on an OBOGS unit supplied by Normalair Garrett Ltd. (NGL) for the Tactical Life Support System (TLSS) and are consistent with the specifications of the Onboard Oxygen Enrichment System (OBOES) of Reference (1).

The best suited location for installation of the HOS in the F-15 aircraft is illustrated in Figure 1-2. This proposed installation for the HOS entails use of the pneumatic supply from the existing anti-fog heat exchanger. In the current system bleed air extracted from upstream of the compressor airflow modulating/shutoff valve enters the hot side of the anti-fog heat exchanger where it is cooled by conditioned air provided by the cabin supply duct. The conditioned air, after absorbing heat, is ducted for anti-fog of transparent surfaces. The bleed air, after rejecting its heat, flows either to the anti-G system and/or to the avionics supply duct where it merges with conditioned air in a mixing muff. A temperature sensor, located in the anti-fog duct downstream of the heat exchanger, controls the anti-fog modulating valve to ensure that air at a minimum temperature of 88 ± 3° F is available for anti-fog.

Installation of the HOS as illustrated in Figure 1-2 results in extraction of bleed air upstream of the modulating valve. The following impacts on the F-15 ECS are envisioned:

(1) for extracted bleed air flows less than or equal to the hot side air flow required for proper anti-fog flow temperature control, no impact on anti-fog. Small effect on total avionics air flow (nominally 60 lbm/min.) and will result in only slight reduction of temperature to avionics.

*Performance specification: Deliver specified (rated O_2 concentration) from 0° to 100°F abd ioerate frin -65°F to 160°F)

(2) for extracted bleed air flows greater than that required for maintenance of anti-fog air temperature, the anti-fog modulating valve will go closed and the anti-fog supply temperature will increase.

In either of the above cases, the avionics controller will signal the avionics hot air modulating valve (temperature and flow compensation) to go open to maintain temperature schedule.

Fluctuation in the temperature and pressure of this chosen pneumatic supply does occur. Performance data from Reference (3) reveals pressures ranging from 21 to 75 psig and temperatures ranging from 43 to 97°F. This variation in pneumatic supply state should be considered when evaluating the performance of the HOS It may be desirable to install an over temperature protection system upstream of the OBOGS. In the event of F-15 ECS failure a probability would exist for high temperature air to flow to the OBOGS. To prevent OBOGS damage a means should be provided to automatically shut off the OBOGS/bleed air supply when the air temperature exceeds some preset threshold valve.

Use of Conditioned Bleed Air

One very promising use of the conditioned bleed air is its use for body cooling and visor demist. Recent studies have been conducted to evaluate the feasibility of an air cooled garment compatible with the Tactical Life Support System. One of the biggest problems faced in the development of the air cooled vest concepts was the requirement for clean conditioned air. This requirement becomes even more stringent if the pneumatic supply for the cooling vest is also to be used for visor demist. The most prohibitive factor in retrofit/installation of the air cooled vest designs in current aircraft is the need for a CBR filter to clean the air delivered. Concerns with the CBR filter include service life (filter must be removed and replaced after a believed threat), sensitivity of the adsorbing media to humidity, and pressure drop through the filter. Use of the conditioned bleed air from the HOS offers an excellent solution to the aforementioned problems associated with the CD filter. The clean conditioned air from the

HOS would dispense with the logistics burden connected with CD filter and would increase the ease with which an air cooled vest/demist system could be retrofit into current aircraft. A broader use of the clean conditioned air from the HOS would be for supply of cabin air. This option, if exercised, would eliminate the need for filtration of ECS air and, in the limit, reduce the amount of equipment the crew is required to wear.

Use of Excess Cooling Potential

The excess cooling potential inherent in the HOS design could be used for avionics, advanced sensor, VHSIC, and VLSIC cooling. In the F-15, the avionics supply air temperature is controlled to 82.5 ± 5°F below 34,500 ft. altitude and to 53 ± 3°F above 34,500 ft. These temperatures are controlled at the downstream side of the radar heat exchanger. Cabin air flow demand is by design given priority over avionics air flow demand. The actuators of the cabin modulating valve and the avionics cold air modulating valve are pneumatically linked, so that the latter valve throttles to reduce avionics cold air flow when the cabin valve reaches the wide open position and cabin air flow still renders insufficient to meet the required flow rate schedule. This pneumatic coupling could be eliminated and the cold bleed air from the HOS could be used to supplement the cabin air supply or could be used to maintain adequate avionics cooling.

TABLE 1-1: F-15 ECS ITEM DESCRIPTION

Item Number	Item Description
103	Refrigeration Package
105	Bleed Air Preconditioning Package
123	(LH) Primary Heat Exchanger Installation Kits
125	(RH) Primary Heat Exchanger Installation Kits
201	Primary Heat Exchanger
203	Primary HX Modulating Bypass Valve
205	Bleed Air Regulator/Shutoff Valve,Primary
207	Bleed Air Regulator/Shutoff Valve (2nd Stage)
209	LH Primary HX Ejector
210	RH Primary HX Ejector
211	Preconditioned Bleed Air Temperature Sensor
217	Compressor Airflow
219	Cooling Turbine
221	Secondary Heat Exchanger
223	Regenerative Heat Exchanger
227	Primary Water Separator
229	Regenerating HX Modulating Valve
231	Avionics Cold Air Modulating Valve
235	Cabin Inlet Air Modulating/Shutoff Valve
237	Cabin Airflow/Temperature Sensor
239	Cabin Hot Air Modulating Valve
241	Cabin Water Separator
249	Cabin Inlet Air Overtemperature Sensor
253	Avionics Overtemperature Sensor
255	Avionics Air Flow/Temperature Sensor
263	Water Separator Discharge temperature Sensor
271	Cabin Controller
273	Avionics Controller
275	Control Box
277	Anti-Fog Modulating Valve
281	Anti-Fog Heat Exchanger
283	Ram Air Temperature Sensor
285	Preconditioned Bleed Air Overtemp Sensor
289	Avionics Hot Air Modulating Valve
293	Inlet Duct
351	Spray Ejector
369	Avionics Emergency Ram Air Converter Valve
379	Solenoid Shutoff Valve
443	Primary HX Ram Air Check Valve
451	Secondary HX Ejector

*ECS items appear in the schematic of Figure 1-1.

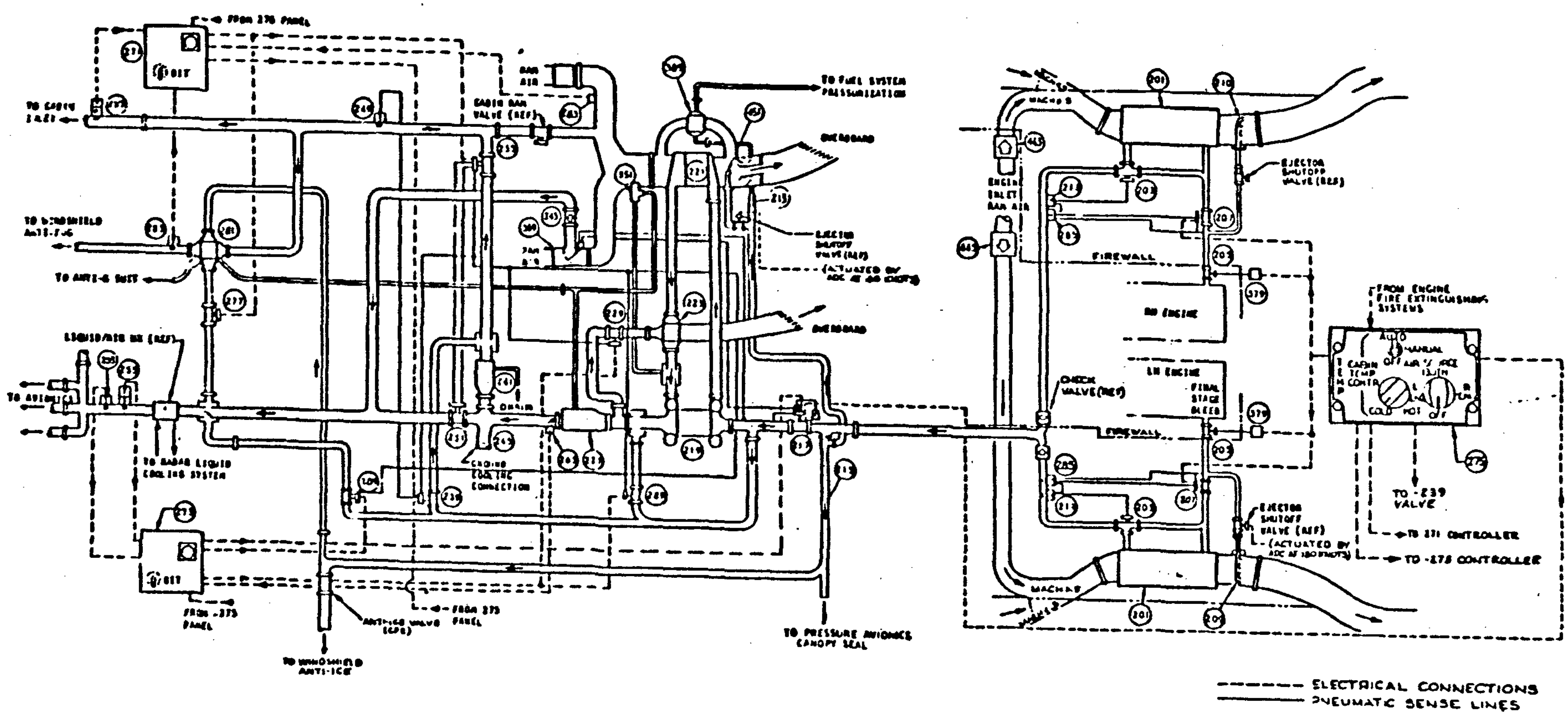


Figure 1-1 F-15 Environmental Control System

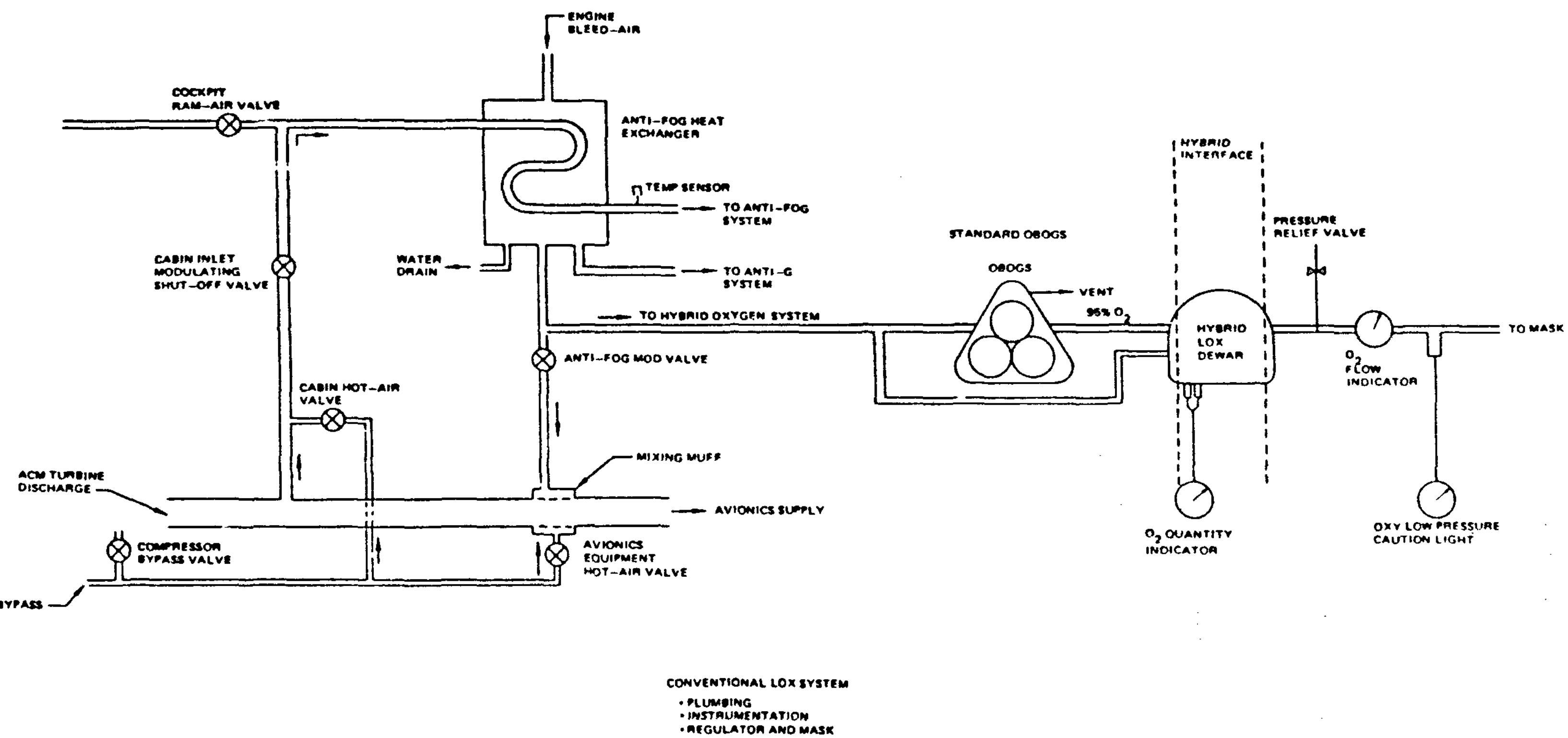


Figure 1–2. F–15 Installation of the Hybrid Oxygen System

APPENDIX 2: Use of tables to generate partial pressures of atmospheric constituents as a function of altitude.

This appendix presents the methodology and resources for generation of partial pressures of atmospheric constituents as a function of geometric altitude. This investigation was conducted per Tom Maimoni's request. Tables 2-1 and 2-2 contained herein are reproduced from Tables 3 and IV, respectively, of Reference 5.

(1) Assumptions:
Per Neil Olien (Department of Commerce Library - research) "Atmosphere contains same proportions of gas species up to 100,000 ft. After this altitude ionization and chemical reactions occur which alter atmospheric composition."

(2) Mole fractions of gas species per Table 2-1 extracted from Reference 5 (U. S. Standard Atmosphere, 1976, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, United States Air Force, NOAA-S/T 76-1562, October 1976).

(3) Use geometric height, Z (ft.), for extraction of total pressure, P(mb), from Table 2-2

(4) Conversion of mb to psia: 14.504 $\text{psia}/_{\text{bar}}$

(5) Sample:

$$P_{\text{total}}\,(MF_{\text{gas species}}) = P_{P\ \text{gas species}}$$

where:
P_{total} = total atmospheric pressure (Table IV)
$MF_{\text{gas species}}$ = mole fraction of species (Table 3)
$P_{P\ \text{gas species}}$ = partial pressure gas species

Example:

@ 1,000 ft.

$P = 9.7716 \times 10^2$ mb

$MF_{N2} = 0.78084$

$$P_{PN2} = (9.7716 \times 10^2)\,(0.78084)\left(\frac{14.504}{10^3}\right)$$

$$P_{PN2} = 11.067 \text{ psia}$$

TABLE 2-1

MOLECULAR WEIGHTS AND FRACTIONAL VOLUME CONCENTRATION OF SEA-LEVEL DRY AIR

Gas Species	Molecular Weight M (kg/kmol)	Fractional Volume F (dimensionless)
N2	28.0134	0.78084
O2	31.9988	.209476
Ar	39.948	.00934
CO2	44.00995	.000314
Ne	20.182	.00001818
He	4.0026	.00000524
Kr	83.80	.00000114
Xe	131.30	.00000087
CH4	16.04303	.000002
H2	2.01594	.0000005

TABLE 2-2

GEOMETRIC ALTITUDES

Table 2-2: Geometric Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
Z (ft)	H (ft)	T (K)	t ($^{\circ}$C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
-1000	-1000	290.131	16.981	1.0504 + 3	1.0366 + 0	1.2613 + 0	1.0296 + 0
-900	-900	289.933	16.783	1.0466	1.0329	1.2576	1.0266
-800	-800	289.735	16.585	1.0428	1.0292	1.2539	1.0236
-700	-700	289.537	16.387	1.0391	1.0255	1.2503	1.0206
-600	-600	289.339	16.189	1.0354	1.0218	1.2467	1.0177
-500	-500	289.140	15.990	1.0316	1.0182	1.2430	1.0147
-400	-400	288.942	15.792	1.0279	1.0145	1.2394	1.0118
-300	-300	288.744	15.594	1.0242	1.0108	1.2358	1.0088
-200	-200	288.546	15.396	1.0205	1.0072	1.2322	1.0059
-100	-100	288.348	15.198	1.0169	1.0036	1.2286	1.0029
0	0	288.150	15.000	1.01325 + 3	1.00000 + 0	1.2250 + 0	1.0000 + 0
100	100	287.952	14.802	1.0095	9.9639 - 1	1.2214	9.9708 - 1
200	200	287.754	14.604	1.0059	9.9279	1.2178	9.9416
300	300	287.556	14.406	1.0023	9.8920	1.2143	9.9125
400	400	287.357	14.207	9.9868 + 2	9.8562	1.2107	9.8835
500	500	287.159	14.009	9.9507	9.8206	1.2072	9.8545
600	600	286.961	13.811	9.9147	9.7850	1.2036	9.8256
700	700	286.763	13.613	9.8788	9.7496	1.2001	9.7968
800	800	286.565	13.415	9.8429	9.7142	1.1966	9.7680
900	900	286.367	13.217	9.8072	9.6790	1.1931	9.7393
1000	1000	286.169	13.019	9.7716 + 2	9.6438 - 1	1.1896 + 0	9.7107 - 1
1100	1100	285.971	12.821	9.7361	9.6088	1.1861	9.6821
1200	1200	285.773	12.623	9.7007	9.5739	1.1826	9.6536
1300	1300	285.574	12.424	9.6654	9.5390	1.1791	9.6251
1400	1400	285.376	12.226	9.6303	9.5043	1.1756	9.5967
1500	1500	285.178	12.028	9.5952	9.4697	1.1721	9.5684
1600	1600	284.980	11.830	9.5602	9.4352	1.1687	9.5402
1700	1700	284.782	11.632	9.5253	9.4008	1.1652	9.5120
1800	1800	284.584	11.434	9.4905	9.3664	1.1618	9.4838
1900	1900	284.386	11.236	9.4559	9.3322	1.1583	9.4558
2000	2000	284.188	11.038	9.4213 + 2	9.2981 - 1	1.1549 + 0	9.4278 - 1
2100	2100	283.990	10.840	9.3868	9.2641	1.1515	9.3999
2200	2200	283.792	10.642	9.3525	9.2302	1.1481	9.3720
2300	2300	283.594	10.444	9.3182	9.1964	1.1447	9.3442
2400	2400	283.396	10.246	9.2841	9.1627	1.1413	9.3164
2500	2500	283.197	10.047	9.2500	9.1291	1.1379	9.2887
2600	2600	282.999	9.849	9.2161	9.0955	1.1345	9.2611
2700	2700	282.801	9.651	9.1822	9.0621	1.1311	9.2336
2800	2800	282.603	9.453	9.1485	9.0288	1.1277	9.2061
2900	2900	282.405	9.255	9.1148	8.9956	1.1244	9.1787
3000	3000	282.207	9.057	9.0813 + 2	8.9625 - 1	1.1210 + 0	9.1513 - 1
3100	3100	282.009	8.859	9.0478	8.9295	1.1177	9.1240
3200	3200	281.811	8.661	9.0145	8.8966	1.1144	9.0967
3300	3299	281.613	8.463	8.9812	8.8638	1.1110	9.0696
3400	3399	281.415	8.265	8.9481	8.8311	1.1077	9.0425
3500	3499	281.217	8.067	8.9150	8.7984	1.1044	9.0154
3600	3599	281.019	7.869	8.8821	8.7659	1.1011	8.9884
3700	3699	280.821	7.671	8.8492	8.7335	1.0978	8.9615
3800	3799	280.623	7.473	8.8165	8.7012	1.0945	8.9346
3900	3899	280.425	7.275	8.7838	8.6689	1.0912	8.9078
4000	3999	280.227	7.077	8.7513 + 2	8.6368 - 1	1.0879 + 0	8.8811 - 1
4100	4099	280.029	6.879	8.7188	8.6048	1.0847	8.8544
4200	4199	279.831	6.681	8.6864	8.5728	1.0814	8.8278
4300	4299	279.632	6.482	8.6542	8.5410	1.0781	8.8012
4400	4399	279.434	6.284	8.6220	8.5093	1.0749	8.7747
4500	4499	279.236	6.086	8.5899	8.4776	1.0717	8.7483
4600	4599	279.038	5.888	8.5580	8.4461	1.0684	8.7219
4700	4699	278.840	5.690	8.5261	8.4146	1.0652	8.6956
4800	4799	278.642	5.492	8.4943	8.3832	1.0620	8.6693
4900	4899	278.444	5.294	8.4626	8.3520	1.0588	8.6431
5000	4999	278.246	5.096	8.4311 + 2	8.3208 - 1	1.0556 + 0	8.6170 - 1
5100	5099	278.048	4.898	8.3996	8.2897	1.0524	8.5909
5200	5199	277.850	4.700	8.3682	8.2587	1.0492	8.5649
5300	5299	277.652	4.502	8.3369	8.2279	1.0460	8.5390
5400	5399	277.454	4.304	8.3057	8.1971	1.0429	8.5131
5500	5499	277.256	4.106	8.2746	8.1664	1.0397	8.4873
5600	5598	277.058	3.908	8.2436	8.1358	1.0365	8.4615
5700	5698	276.860	3.710	8.2126	8.1052	1.0334	8.4358
5800	5798	276.662	3.512	8.1818	8.0748	1.0302	8.4102
5900	5898	276.464	3.314	8.1511	8.0445	1.0271	8.3846
6000	5998	276.266	3.116	8.1204 + 2	8.0142 - 1	1.0240 + 0	8.3590 - 1
6100	6098	276.068	2.918	8.0899	7.9841	1.0209	8.3336
6200	6198	275.870	2.720	8.0594	7.9541	1.0178	8.3082
6300	6298	275.672	2.522	8.0291	7.9241	1.0146	8.2828
6400	6398	275.474	2.324	7.9988	7.8942	1.0115	8.2575
6500	6498	275.276	2.126	7.9687	7.8644	1.0085	8.2323
6600	6598	275.078	1.928	7.9386	7.8348	1.0054	8.2071
6700	6698	274.880	1.730	7.9086	7.8052	1.0023	8.1820
6800	6798	274.682	1.532	7.8787	7.7757	9.9923 - 1	8.1570
6900	6898	274.484	1.334	7.8489	7.7463	9.9617	8.1320

Table 2-2: Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m³)	ρ/ρ_0
7000	7002	274.282	1.132	7.8185 + 2	7.7162 - 1	9.9304 - 1	8.1065 - 1
7100	7102	274.084	.934	7.7889	7.6870	9.8999	8.0816
7200	7202	273.886	.736	7.7593	7.6578	9.8695	8.0567
7300	7303	273.687	.537	7.7299	7.6288	9.8391	8.0320
7400	7403	273.489	.339	7.7005	7.5998	9.8089	8.0072
7500	7503	273.291	.141	7.6712	7.5709	9.7787	7.9826
7600	7603	273.093	-.057	7.6420	7.542[illegible]	9.7485	7.9580
7700	7703	272.895	-.255	7.6129	7.5134	9.7185	7.9334
7800	7803	272.697	-.453	7.5839	7.4848	9.6885	7.9090
7900	7903	272.499	-.651	7.5550	7.4562	9.6586	7.8845
8000	8003	272.301	-.849	7.5262 + 2	7.4278 - 1	9.6287 - 1	7.8602 - 1
8100	8103	272.102	-1.048	7.4975	7.3994	9.5989	7.8359
8200	8203	271.904	-1.246	7.4688	7.3711	9.5692	7.8116
8300	8303	271.706	-1.444	7.4403	7.3430	9.5396	7.7874
8400	8403	271.508	-1.642	7.4118	7.3149	9.5100	7.7633
8500	8503	271.310	-1.840	7.3834	7.2868	9.4805	7.7392
8600	8604	271.112	-2.038	7.3551	7.2589	9.4511	7.7152
8700	8704	270.914	-2.236	7.3269	7.2311	9.4217	7.6912
8800	8804	270.716	-2.434	7.2988	7.2033	9.3924	7.6673
8900	8904	270.518	-2.632	7.2707	7.1757	9.3632	7.6434
9000	9004	270.319	-2.831	7.2428 + 2	7.1481 - 1	9.3341 - 1	7.6196 - 1
9100	9104	270.121	-3.029	7.2149	7.1206	9.3050	7.5959
9200	9204	269.923	-3.227	7.1872	7.0932	9.2760	7.5722
9300	9304	269.725	-3.425	7.1595	7.0659	9.2470	7.5486
9400	9404	269.527	-3.623	7.1319	7.0386	9.2182	7.5250
9500	9504	269.329	-3.821	7.1044	7.0115	9.1894	7.5015
9600	9604	269.131	-4.019	7.0770	6.9844	9.1606	7.4781
9700	9705	268.933	-4.217	7.0496	6.9574	9.1320	7.4547
9800	9805	268.734	-4.416	7.0224	6.9305	9.1034	7.4313
9900	9905	268.536	-4.614	6.9952	6.9037	9.0748	7.4080
10000	10005	268.338	-4.812	6.9681 + 2	6.8770 - 1	9.0464 - 1	7.3848 - 1
10100	10105	268.140	-5.010	6.9411	6.8504	9.0180	7.3616
10200	10205	267.942	-5.208	6.9142	6.8238	8.9897	7.3385
10300	10305	267.744	-5.406	6.8874	6.7973	8.9614	7.3154
10400	10405	267.546	-5.604	6.8606	6.7709	8.9332	7.2924
10500	10505	267.348	-5.802	6.8340	6.7446	8.9051	7.2695
10600	10605	267.149	-6.001	6.8074	6.7184	8.8770	7.2466
10700	10705	266.951	-6.199	6.7809	6.6922	8.8491	7.2237
10800	10806	266.753	-6.397	6.7545	6.6662	8.8211	7.2009
10900	10906	266.555	-6.595	6.7282	6.6402	8.7933	7.1782
11000	11006	266.357	-6.793	6.7019 + 2	6.6143 - 1	8.7655 - 1	7.1555 - 1
11100	11106	266.159	-6.991	6.6758	6.5885	8.7378	7.1329
11200	11206	265.961	-7.189	6.6497	6.5627	8.7102	7.1103
11300	11306	265.763	-7.387	6.6237	6.5371	8.6826	7.0878
11400	11406	265.565	-7.585	6.5978	6.5115	8.6551	7.0654
11500	11506	265.366	-7.784	6.5720	6.4860	8.6276	7.0429
11600	11606	265.168	-7.982	6.5462	6.4606	8.6002	7.0206
11700	11707	264.970	-8.180	6.5205	6.4353	8.5729	6.9983
11800	11807	264.772	-8.378	6.4950	6.4100	8.5457	6.9761
11900	11907	264.574	-8.576	6.4695	6.3849	8.5185	6.9539
12000	12007	264.376	-8.774	6.4440 + 2	6.3598 - 1	8.4914 - 1	6.9317 - 1
12100	12107	264.178	-8.972	6.4187	6.3348	8.4643	6.9097
12200	12207	263.980	-9.170	6.3934	6.3098	8.4373	6.8876
12300	12307	263.781	-9.369	6.3683	6.2850	8.4104	6.8657
12400	12407	263.583	-9.567	6.3432	6.2602	8.3836	6.8437
12500	12507	263.385	-9.765	6.3181	6.2355	8.3568	6.8219
12600	12608	263.187	-9.963	6.2932	6.2109	8.3301	6.8001
12700	12708	262.989	-10.161	6.2683	6.1864	8.3034	6.7783
12800	12808	262.791	-10.359	6.2435	6.1619	8.2768	6.7566
12900	12908	262.593	-10.557	6.2189	6.1375	8.2503	6.7349
13000	13008	262.395	-10.755	6.1942 + 2	6.1132 - 1	8.2238 - 1	6.7133 - 1
13100	13108	262.196	-10.954	6.1697	6.0890	8.1975	6.6918
13200	13208	261.998	-11.152	6.1452	6.0649	8.1711	6.6703
13300	13308	261.800	-11.350	6.1209	6.0408	8.1449	6.6489
13400	13409	261.602	-11.548	6.0965	6.0168	8.1187	6.6275
13500	13509	261.404	-11.746	6.0723	5.9929	8.0925	6.6061
13600	13609	261.206	-11.944	6.0482	5.9691	8.0665	6.5849
13700	13709	261.008	-12.142	6.0241	5.9453	8.0404	6.5636
13800	13809	260.810	-12.340	6.0001	5.9216	8.0145	6.5425
13900	13909	260.612	-12.538	5.9762	5.8980	7.9886	6.5213
14000	14009	260.413	-12.737	5.9523 + 2	5.8745 - 1	7.9628 - 1	6.5003 - 1
14100	14110	260.215	-12.935	5.9286	5.8511	7.9371	6.4792
14200	14210	260.017	-13.133	5.9049	5.8277	7.9114	6.4583
14300	14310	259.819	-13.331	5.8813	5.8044	7.8858	6.4373
14400	14410	259.621	-13.529	5.8578	5.7811	7.8602	6.4165
14500	14510	259.423	-13.727	5.8343	5.7580	7.8347	6.3957
14600	14610	259.225	-13.925	5.8109	5.7349	7.8093	6.3749
14700	14710	259.027	-14.123	5.7876	5.7119	7.7839	6.3542
14800	14811	258.828	-14.322	5.7644	5.6890	7.7586	6.3335
14900	14911	258.630	-14.520	5.7412	5.6661	7.7333	6.3129

Table 2-2: Geometric Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
Z (ft)	H (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
7000	6998	274.286	1.136	7.8192 + 2	7.7169 - 1	9.9311 - 1	8.1070 - 1
7100	7098	274.088	.938	7.7896	7.6877	9.9007	8.0822
7200	7198	273.890	.740	7.7600	7.6586	9.8703	8.0573
7300	7297	273.692	.542	7.7306	7.6295	9.8399	8.0326
7400	7397	273.494	.344	7.7013	7.6005	9.8097	8.0079
7500	7497	273.296	.146	7.6720	7.5717	9.7795	7.9832
7600	7597	273.098	-.052	7.6428	7.5429	9.7494	7.9587
7700	7697	272.900	-.250	7.6138	7.5142	9.7193	7.9341
7800	7797	272.702	-.448	7.5848	7.4856	9.6894	7.9097
7900	7897	272.504	-.646	7.5559	7.4571	9.6595	7.8853
8000	7997	272.306	-.844	7.5271 + 2	7.4286 - 1	9.6296 - 1	7.8609 - 1
8100	8097	272.108	-1.042	7.4984	7.4003	9.5999	7.8366
8200	8197	271.910	-1.240	7.4697	7.3720	9.5702	7.8124
8300	8297	271.712	-1.438	7.4412	7.3439	9.5406	7.7882
8400	8397	271.514	-1.636	7.4127	7.3158	9.5110	7.7641
8500	8497	271.317	-1.833	7.3844	7.2878	9.4815	7.7400
8600	8596	271.119	-2.031	7.3561	7.2599	9.4521	7.7160
8700	8696	270.921	-2.229	7.3279	7.2321	9.4228	7.6921
8800	8796	270.723	-2.427	7.2998	7.2044	9.3935	7.6682
8900	8896	270.525	-2.625	7.2718	7.1767	9.3643	7.6443
9000	8996	270.327	-2.823	7.2439 + 2	7.1492 - 1	9.3352 - 1	7.6206 - 1
9100	9096	270.129	-3.021	7.2160	7.1217	9.3061	7.5968
9200	9196	269.931	-3.219	7.1883	7.0943	9.2772	7.5732
9300	9296	269.733	-3.417	7.1606	7.0670	9.2482	7.5496
9400	9396	269.535	-3.615	7.1331	7.0398	9.2194	7.5260
9500	9496	269.337	-3.813	7.1056	7.0127	9.1906	7.5025
9600	9596	269.139	-4.011	7.0782	6.9856	9.1619	7.4791
9700	9695	268.941	-4.209	7.0509	6.9586	9.1333	7.4557
9800	9795	268.743	-4.407	7.0236	6.9318	9.1047	7.4324
9900	9895	268.545	-4.605	6.9965	6.9050	9.0762	7.4091
10000	9995	268.347	-4.803	6.9694 + 2	6.8783 - 1	9.0477 - 1	7.3859 - 1
10100	10095	268.149	-5.001	6.9424	6.8516	9.0194	7.3627
10200	10195	267.952	-5.198	6.9155	6.8251	8.9911	7.3396
10300	10295	267.754	-5.396	6.8887	6.7987	8.9628	7.3166
10400	10395	267.556	-5.594	6.8620	6.7723	8.9347	7.2936
10500	10495	267.358	-5.792	6.8354	6.7460	8.9066	7.2707
10600	10595	267.160	-5.990	6.8088	6.7198	8.8786	7.2478
10700	10695	266.962	-6.188	6.7824	6.6937	8.8506	7.2250
10800	10794	266.764	-6.386	6.7560	6.6676	8.8227	7.2022
10900	10894	266.566	-6.584	6.7297	6.6417	8.7949	7.1795
11000	10994	266.368	-6.782	6.7034 + 2	6.6158 - 1	8.7671 - 1	7.1568 - 1
11100	11094	266.170	-6.980	6.6773	6.5900	8.7394	7.1342
11200	11194	265.972	-7.178	6.6513	6.5643	8.7118	7.1117
11300	11294	265.774	-7.376	6.6253	6.5386	8.6843	7.0892
11400	11394	265.577	-7.573	6.5994	6.5131	8.6568	7.0667
11500	11494	265.379	-7.771	6.5736	6.4876	8.6294	7.0444
11600	11594	265.181	-7.969	6.5479	6.4622	8.6020	7.0220
11700	11693	264.983	-8.167	6.5222	6.4369	8.5747	6.9998
11800	11793	264.785	-8.365	6.4967	6.4117	8.5475	6.9775
11900	11893	264.587	-8.563	6.4712	6.3866	8.5203	6.9554
12000	11993	264.389	-8.761	6.4458 + 2	6.3615 - 1	8.4933 - 1	6.9333 - 1
12100	12093	264.191	-8.959	6.4205	6.3365	8.4662	6.9112
12200	12193	263.993	-9.157	6.3952	6.3116	8.4393	6.8892
12300	12293	263.795	-9.355	6.3701	6.2868	8.4124	6.8672
12400	12393	263.598	-9.552	6.3450	6.2620	8.3856	6.8453
12500	12493	263.400	-9.750	6.3200	6.2374	8.3588	6.8235
12600	12592	263.202	-9.948	6.2951	6.2128	8.3321	6.8017
12700	12692	263.004	-10.146	6.2703	6.1883	8.3055	6.7800
12800	12792	262.806	-10.344	6.2455	6.1638	8.2789	6.7583
12900	12892	262.608	-10.542	6.2208	6.1395	8.2524	6.7367
13000	12992	262.410	-10.740	6.1962 + 2	6.1152 - 1	8.2260 - 1	6.7151 - 1
13100	13092	262.212	-10.938	6.1717	6.0910	8.1996	6.6936
13200	13192	262.015	-11.135	6.1473	6.0669	8.1733	6.6721
13300	13292	261.817	-11.333	6.1229	6.0428	8.1471	6.6507
13400	13391	261.619	-11.531	6.0986	6.0169	8.1209	6.6293
13500	13491	261.421	-11.729	6.0744	5.9950	8.0948	6.6080
13600	13591	261.223	-11.927	6.0503	5.9712	8.0688	6.5867
13700	13691	261.025	-12.125	6.0263	5.9474	8.0428	6.5655
13800	13791	260.827	-12.323	6.0023	5.9238	8.0169	6.5444
13900	13891	260.630	-12.520	5.9784	5.9002	7.9910	6.5233
14000	13991	260.432	-12.718	5.9546 + 2	5.8767 - 1	7.9652 - 1	6.5022 - 1
14100	14090	260.234	-12.916	5.9308	5.8533	7.9395	6.4812
14200	14190	260.036	-13.114	5.9072	5.8299	7.9139	6.4603
14300	14290	259.838	-13.312	5.8836	5.8066	7.8883	6.4394
14400	14390	259.640	-13.510	5.8601	5.7834	7.8627	6.4186
14500	14490	259.442	-13.708	5.8367	5.7603	7.8373	6.3978
14600	14590	259.245	-13.905	5.8133	5.7373	7.8119	6.3770
14700	14690	259.047	-14.103	5.7900	5.7143	7.7865	6.3563
14800	14790	258.849	-14.301	5.7668	5.6914	7.7612	6.3357
14900	14889	258.651	-14.499	5.7437	5.6686	7.7360	6.3151

Table 2-2: Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	(kg/m³)	ρ/ρ_0
15000	15011	258.432	-14.718	5.7182 + 2	5.6434 - 1	7.7082 - 1	6.2924 - 1
15100	15111	258.234	-14.916	5.6951	5.6207	7.6830	6.2719
15200	15211	258.036	-15.114	5.6722	5.5980	7.6580	6.2514
15300	15311	257.838	-15.312	5.6494	5.5755	7.6330	6.2310
15400	15411	257.640	-15.510	5.6266	5.5530	7.6081	6.2107
15500	15512	257.442	-15.708	5.6039	5.5306	7.5832	6.1904
15600	15612	257.243	-15.907	5.5813	5.5083	7.5584	6.1701
15700	15712	257.045	-16.105	5.5587	5.4860	7.5337	6.1499
15800	15812	256.847	-16.303	5.5362	5.4638	7.5090	6.1298
15900	15912	256.649	-16.501	5.5138	5.4417	7.4844	6.1097
16000	16012	256.451	-16.699	5.4915 + 2	5.4197 - 1	7.4598 - 1	6.0896 - 1
16100	16112	256.253	-16.897	5.4692	5.3977	7.4353	6.0696
16200	16213	256.055	-17.095	5.4470	5.3758	7.4109	6.0497
16300	16313	255.857	-17.293	5.4249	5.3540	7.3865	6.0298
16400	16413	255.659	-17.491	5.4029	5.3322	7.3622	6.0099
16500	16513	255.460	-17.690	5.3809	5.3105	7.3379	5.9901
16600	16613	255.262	-17.888	5.3590	5.2889	7.3137	5.9734
16700	16713	255.064	-18.086	5.3372	5.2674	7.2896	5.9507
16800	16814	254.866	-18.284	5.3154	5.2459	7.2655	5.9311
16900	16914	254.668	-18.482	5.2937	5.2245	7.2415	5.9115
17000	17014	254.470	-18.680	5.2721 + 2	5.2032 - 1	7.2176 - 1	5.8919 - 1
17100	17114	254.272	-18.878	5.2506	5.1819	7.1937	5.8724
17200	17214	254.074	-19.076	5.2291	5.1607	7.1699	5.8530
17300	17314	253.875	-19.275	5.2077	5.1396	7.1461	5.8336
17400	17415	253.677	-19.473	5.1864	5.1186	7.1224	5.8142
17500	17515	253.479	-19.671	5.1652	5.0976	7.0988	5.7949
17600	17615	253.281	-19.869	5.1440	5.0767	7.0752	5.7757
17700	17715	253.083	-20.067	5.1229	5.0559	7.0517	5.7565
17800	17815	252.885	-20.265	5.1018	5.0351	7.0282	5.7373
17900	17915	252.687	-20.463	5.0808	5.0144	7.0048	5.7182
18000	18016	252.489	-20.661	5.0599 + 2	4.9938 - 1	6.9815 - 1	5.6991 - 1
18100	18116	252.290	-20.860	5.0391	4.9732	6.9582	5.6801
18200	18216	252.092	-21.058	5.0183	4.9527	6.9349	5.6612
18300	18316	251.894	-21.256	4.9976	4.9323	6.9118	5.6423
18400	18416	251.696	-21.454	4.9770	4.9119	6.8887	5.6234
18500	18516	251.498	-21.652	4.9565	4.8916	6.8656	5.6046
18600	18617	251.300	-21.850	4.9360	4.8714	6.8426	5.5858
18700	18717	251.102	-22.048	4.9156	4.8513	6.8197	5.5671
18800	18817	250.904	-22.246	4.8952	4.8312	6.7968	5.5484
18900	18917	250.706	-22.444	4.8749	4.8112	6.7740	5.5298
19000	19017	250.507	-22.643	4.8547 + 2	4.7912 - 1	6.7513 - 1	5.5112 - 1
19100	19118	250.309	-22.841	4.8346	4.7713	6.7286	5.4927
19200	19218	250.111	-23.039	4.8145	4.7515	6.7059	5.4742
19300	19318	249.913	-23.237	4.7945	4.7318	6.6834	5.4558
19400	19418	249.715	-23.435	4.7745	4.7121	6.6608	5.4374
19500	19518	249.517	-23.633	4.7547	4.6925	6.6384	5.4191
19600	19618	249.319	-23.831	4.7349	4.6729	6.6160	5.4008
19700	19719	249.121	-24.029	4.7151	4.6534	6.5936	5.3826
19800	19819	248.922	-24.228	4.6954	4.6340	6.5713	5.3644
19900	19919	248.724	-24.426	4.6758	4.6147	6.5491	5.3462
20000	20019	248.526	-24.624	4.6563 + 2	4.5954 - 1	6.5269 - 1	5.3281 - 1
20100	20119	248.328	-24.822	4.6368	4.5762	6.5048	5.3101
20200	20220	248.130	-25.020	4.6174	4.5570	6.4828	5.2921
20300	20320	247.932	-25.218	4.5980	4.5379	6.4608	5.2741
20400	20420	247.734	-25.416	4.5788	4.5189	6.4388	5.2562
20500	20520	247.536	-25.614	4.5596	4.4999	6.4169	5.2383
20600	20620	247.337	-25.813	4.5404	4.4810	6.3951	5.2205
20700	20721	247.139	-26.011	4.5213	4.4622	6.3733	5.2027
20800	20821	246.941	-26.209	4.5023	4.4434	6.3516	5.1850
20900	20921	246.743	-26.407	4.4834	4.4247	6.3300	5.1673
21000	21021	246.545	-26.605	4.4645 + 2	4.4061 - 1	6.3084 - 1	5.1497 - 1
21100	21121	246.347	-26.803	4.4456	4.3875	6.2868	5.1321
21200	21222	246.149	-27.001	4.4269	4.3690	6.2653	5.1146
21300	21322	245.951	-27.199	4.4082	4.3505	6.2439	5.0971
21400	21422	245.753	-27.397	4.3896	4.3322	6.2225	5.0796
21500	21522	245.554	-27.596	4.3710	4.3138	6.2012	5.0622
21600	21622	245.356	-27.794	4.3525	4.2956	6.1799	5.0448
21700	21723	245.158	-27.992	4.3340	4.2774	6.1587	5.0275
21800	21823	244.960	-28.190	4.3157	4.2592	6.1376	5.0103
21900	21923	244.762	-28.388	4.2974	4.2412	6.1165	4.9930
22000	22023	244.564	-28.586	4.2791 + 2	4.2231 - 1	6.0954 - 1	4.9759 - 1
22100	22123	244.366	-28.784	4.2609	4.2052	6.0744	4.9587
22200	22224	244.168	-28.982	4.2428	4.1873	6.0535	4.9416
22300	22324	243.969	-29.181	4.2247	4.1695	6.0326	4.9246
22400	22424	243.771	-29.379	4.2067	4.1517	6.0118	4.9076
22500	22524	243.573	-29.577	4.1888	4.1340	5.9910	4.8906
22600	22625	243.375	-29.775	4.1709	4.1164	5.9703	4.8737
22700	22725	243.177	-29.973	4.1531	4.0988	5.9497	4.8569
22800	22825	242.979	-30.171	4.1353	4.0813	5.9291	4.8401
22900	22925	242.781	-30.369	4.1177	4.0638	5.9085	4.8233

Table 2-2: Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
23000	23025	242.583	-30.567	4.1000 + 2	4.0464 - 1	5.8880 - 1	4.8066 - 1
23100	23126	242.384	-30.766	4.0825	4.0291	5.8676	4.7899
23200	23226	242.186	-30.964	4.0649	4.0118	5.8472	4.7732
23300	23326	241.988	-31.162	4.0475	3.9946	5.8269	4.7566
23400	23426	241.790	-31.360	4.0301	3.9774	5.8066	4.7401
23500	23527	241.592	-31.558	4.0128	3.9603	5.7864	4.7236
23600	23627	241.394	-31.756	3.9955	3.9433	5.7662	4.7071
23700	23727	241.196	-31.954	3.9783	3.9263	5.7461	4.6907
23800	23827	240.998	-32.152	3.9612	3.9094	5.7260	4.6743
23900	23927	240.800	-32.350	3.9441	3.8925	5.7060	4.6580
24000	24028	240.601	-32.549	3.9271 + 2	3.8757 - 1	5.6861 - 1	4.6417 - 1
24100	24128	240.403	-32.747	3.9101	3.8590	5.6662	4.6254
24200	24228	240.205	-32.945	3.8932	3.8423	5.6463	4.6092
24300	24328	240.007	-33.143	3.8763	3.8256	5.6265	4.5931
24400	24429	239.809	-33.341	3.8595	3.8091	5.6068	4.5770
24500	24529	239.611	-33.539	3.8428	3.7926	5.5871	4.5609
24600	24629	239.413	-33.737	3.8261	3.7761	5.5675	4.5449
24700	24729	239.215	-33.935	3.8095	3.7597	5.5479	4.5289
24800	24830	239.016	-34.134	3.7930	3.7434	5.5284	4.5129
24900	24930	238.818	-34.332	3.7765	3.7271	5.5089	4.4971
25000	25030	238.620	-34.530	3.7600 + 2	3.7109 - 1	5.4895 - 1	4.4812 - 1
25100	25130	238.422	-34.728	3.7437	3.6947	5.4701	4.4654
25200	25230	238.224	-34.926	3.7273	3.6786	5.4508	4.4496
25300	25331	238.026	-35.124	3.7111	3.6625	5.4315	4.4339
25400	25431	237.828	-35.322	3.6949	3.6466	5.4123	4.4182
25500	25531	237.630	-35.520	3.6787	3.6306	5.3931	4.4026
25600	25631	237.431	-35.719	3.6626	3.6147	5.3740	4.3870
25700	25732	237.233	-35.917	3.6466	3.5989	5.3550	4.3714
25800	25832	237.035	-36.115	3.6306	3.5831	5.3360	4.3559
25900	25932	236.837	-36.313	3.6147	3.5674	5.3170	4.3404
26000	26032	236.639	-36.511	3.5988 + 2	3.5518 - 1	5.2981 - 1	4.3250 - 1
26100	26133	236.441	-36.709	3.5830	3.5362	5.2792	4.3096
26200	26233	236.243	-36.907	3.5673	3.5206	5.2604	4.2942
26300	26333	236.045	-37.105	3.5516	3.5051	5.2417	4.2789
26400	26433	235.847	-37.303	3.5359	3.4897	5.2230	4.2637
26500	26534	235.648	-37.502	3.5204	3.[illegible]743	5.2043	4.2484
26600	26634	235.450	-37.700	3.5048	3.4590	5.1858	4.2333
26700	26734	235.252	-37.898	3.4894	3.4437	5.1672	4.2181
26800	26834	235.054	-38.096	3.4739	3.4285	5.1487	4.2030
26900	26935	234.856	-38.294	3.4586	3.4133	5.1303	4.1880
27000	27035	234.658	-38.492	3.4433 + 2	3.3982 - 1	5.1119 - 1	4.1730 - 1
27100	27135	234.460	-38.690	3.4280	3.3832	5.0935	4.1580
27200	27236	234.262	-38.888	3.4128	3.3682	5.0752	4.1431
27300	27336	234.063	-39.087	3.3977	3.3532	5.0570	4.1282
27400	27436	233.865	-39.285	3.3826	3.3384	5.0388	4.1133
27500	27536	233.667	-39.483	3.3676	3.3235	5.0207	4.0985
27600	27637	233.469	-39.681	3.3526	3.3087	5.0026	4.0837
27700	27737	233.271	-39.879	3.3376	3.2940	4.9845	4.0690
27800	27837	233.073	-40.077	3.3228	3.2793	4.9665	4.0543
27900	27937	232.875	-40.275	3.3080	3.2647	4.9486	4.0397
28000	28038	232.677	-40.473	3.2932 + 2	3.2501 - 1	4.9307 - 1	4.0251 - 1
28100	28138	232.478	-40.672	3.2785	3.2356	4.9129	4.0105
28200	28238	232.280	-40.870	3.[illegible]638	3.2211	4.8951	3.9960
28300	28338	232.082	-41.068	3.2492	3.2067	4.8773	3.9815
28400	28439	231.884	-41.266	3.2347	3.1924	4.8596	3.9670
28500	28539	231.686	-41.464	3.2202	3.1781	4.8420	3.9526
28600	28639	231.488	-41.662	3.2057	3.1638	4.8244	3.9383
28700	28740	231.290	-41.860	3.1913	3.1496	4.8068	3.9239
28800	28840	231.092	-42.058	3.1770	3.1354	4.7893	3.9097
28900	28940	230.894	-42.256	3.1627	3.1213	4.7719	3.8954
29000	29040	230.695	-42.455	3.1485 + 2	3.1073 - 1	4.7545 - 1	3.8812 - 1
29100	29141	230.497	-42.653	3.1343	3.0933	4.7371	3.8670
29200	29241	230.299	-42.851	3.1201	3.0793	4.7198	3.8529
29300	29341	230.101	-43.049	3.1061	3.0654	4.7026	3.8388
29400	2944[illegible]	229.903	-43.247	3.0920	3.0516	4.6854	3.8248
29500	29542	229.705	-43.445	3.0780	3.0378	4.6682	3.8108
29600	29642	229.507	-43.643	3.0641	3.0240	4.6511	3.7968
29700	29742	229.309	-43.841	3.0502	3.0103	4.6340	3.7829
29800	29843	229.110	-44.040	3.0364	2.9967	4.6170	3.7690
29900	29943	228.912	-44.238	3.0226	2.9831	4.6000	3.7551
30000	30043	228.714	-44.436	3.0089 + 2	2.9696 - 1	4.5831 - 1	3.7413 - 1
30100	30144	228.516	-44.634	2.9952	2.9561	4.5663	3.7276
30200	30244	228.318	-44.832	2.9816	2.9426	4.5494	3.7138
30300	30344	228.120	-45.030	2.9680	2.9292	4.5327	3.7001
30400	30444	227.922	-45.228	2.9545	2.9159	4.5159	3.6865
30500	30545	227.724	-45.426	2.9410	2.9026	4.4992	3.6728
30600	30645	227.525	-45.625	2.9275	2.8893	4.4826	3.6593
30700	30745	227.327	-45.823	2.9142	2.8761	4.4660	3.6457
30800	30846	227.129	-46.021	2.9009	2.8630	4.4495	3.6322
30900	30946	226.931	-46.219	2.8876	2.8499	4.[illegible]	3.6188

Table 2-2 Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
31000	31046	226.733	-46.417	2.8744 + 2	2.8368 - 1	4.4165 - 1	3.6053 - 1
31100	31146	226.535	-46.615	2.8612	2.8238	4.4001	3.5919
31200	31247	226.337	-46.813	2.8481	2.8109	4.3838	3.5786
31300	31347	226.139	-47.011	2.8350	2.7980	4.3675	3.5653
31400	31447	225.941	-47.209	2.8220	2.7851	4.3512	3.5520
31500	31548	225.742	-47.408	2.8090	2.7723	4.3350	3.5388
31600	31648	225.544	-47.606	2.7961	2.7595	4.3188	3.5256
31700	31748	225.346	-47.804	2.7832	2.7468	4.3027	3.5124
31800	31849	225.148	-48.002	2.7704	2.7341	4.2866	3.4993
31900	31949	224.950	-48.200	2.7576	2.7215	4.2706	3.4862
32000	32049	224.752	-48.398	2.7448 + 2	2.7089 - 1	4.2546 - 1	3.4732 - 1
32100	32149	224.554	-48.596	2.7321	2.6964	4.2387	3.4601
32200	32250	224.356	-48.794	2.7195	2.6839	4.2228	3.4472
32300	32350	224.157	-48.993	2.7069	2.6715	4.2069	3.4342
32400	32450	223.959	-49.191	2.6944	2.6591	4.1911	3.4213
32500	32551	223.761	-49.389	2.6818	2.6468	4.1754	3.4085
32600	32651	223.563	-49.587	2.6694	2.6345	4.1597	3.3956
32700	32751	223.365	-49.785	2.6570	2.6222	4.1440	3.3829
32800	32852	223.167	-49.983	2.6446	2.6100	4.1284	3.3701
32900	32952	222.969	-50.181	2.6323	2.5979	4.1128	3.3574
33000	33052	222.771	-50.379	2.6200 + 2	2.5858 - 1	4.0973 - 1	3.3447 - 1
33100	33153	222.572	-50.578	2.6078	2.5737	4.0818	3.3321
33200	33253	222.374	-50.776	2.5956	2.5617	4.0663	3.3195
33300	33353	222.176	-50.974	2.5835	2.5497	4.0510	3.3069
33400	33454	221.978	-51.172	2.5714	2.5378	4.0356	3.2944
33500	33554	221.780	-51.370	2.5594	2.5259	4.0203	3.2819
33600	33654	221.582	-51.568	2.5474	2.5141	4.0050	3.2694
33700	33755	221.384	-51.766	2.5354	2.5023	3.9898	3.2570
33800	33855	221.186	-51.964	2.5235	2.4905	3.9746	3.2446
33900	33955	220.988	-52.162	2.5117	2.4788	3.9595	3.2323
34000	34056	220.789	-52.361	2.4999 + 2	2.4672 - 1	3.9444 - 1	3.2199 - 1
34100	34156	220.591	-52.559	2.4881	2.4555	3.9294	3.2077
34200	34256	220.393	-52.757	2.4764	2.4440	3.9144	3.1954
34300	34357	220.195	-52.955	2.4647	2.4325	3.8994	3.1832
34400	34457	219.997	-53.153	2.4531	2.4210	3.8845	3.1710
34500	34557	219.799	-53.351	2.4415	2.4095	3.8697	3.1589
34600	34658	219.601	-53.549	2.4299	2.3981	3.8548	3.1468
34700	34758	219.403	-53.747	2.4184	2.3868	3.8401	3.1347
34800	34858	219.204	-53.946	2.4070	2.3755	3.8253	3.1227
34900	34959	219.006	-54.144	2.3956	2.3642	3.8106	3.1107
35000	35059	218.808	-54.342	2.3842 + 2	2.3530 - 1	3.7960 - 1	3.0988 - 1
35200	35260	218.412	-54.738	2.3616	2.3307	3.7668	3.0749
35400	35460	218.016	-55.134	2.3391	2.3086	3.7378	3.0513
35600	35661	217.619	-55.531	2.3169	2.2866	3.7090	3.0277
35800	35862	217.223	-55.927	2.2948	2.2648	3.6803	3.0043
36000	36062	216.827	-56.323	2.2729	2.2432	3.6518	2.9811
36200	36263	216.650	-56.500	2.2511	2.2217	3.6199	2.9550
36400	36464	216.650	-56.500	2.2296	2.2004	3.5852	2.9267
36600	36664	216.650	-56.500	2.2083	2.1794	3.5509	2.8987
36800	36865	216.650	-56.500	2.1872	2.1585	3.5170	2.8710
37000	37066	216.650	-56.500	2.1662 + 2	2.1379 - 1	3.4833 - 1	2.8435 - 1
37200	37266	216.650	-56.500	2.1455	2.1174	3.4500	2.8163
37400	37467	216.650	-56.500	2.1250	2.0972	3.4170	2.7894
37600	37668	216.650	-56.500	2.1046	2.0771	3.3843	2.7627
37800	37869	216.650	-56.500	2.0845	2.0573	3.3519	2.7363
38000	38069	216.650	-56.500	2.0646	2.0376	3.3199	2.7101
38200	38270	216.650	-56.500	2.0448	2.0181	3.2881	2.6842
38400	38471	216.650	-56.500	2.0253	1.9988	3.2566	2.6585
38600	38672	216.650	-56.500	2.0059	1.9796	3.2255	2.6330
38800	38872	216.650	-56.500	1.9867	1.9607	3.1946	2.6079
39000	39073	216.650	-56.500	1.9677 + 2	1.9420 - 1	3.1641 - 1	2.5829 - 1
39200	39274	216.650	-56.500	1.9489	1.9234	3.1338	2.5582
39400	39475	216.650	-56.500	1.9302	1.9050	3.1038	2.5337
39600	39675	216.650	-56.500	1.9117	1.8867	3.0741	2.5095
39800	39876	216.650	-56.500	1.8935	1.8687	3.0447	2.4855
40000	40077	216.650	-56.500	1.8753	1.8508	3.0156	2.4617
40200	40278	216.650	-56.500	1.8574	1.8331	2.9867	2.4382
40400	40478	216.650	-56.500	1.8396	1.8156	2.9582	2.4148
40600	40679	216.650	-56.500	1.8220	1.7982	2.9299	2.3917
40800	40880	216.650	-56.500	1.8046	1.7810	2.9018	2.3688
41000	41081	216.650	-56.500	1.7873 + 2	1.7640 - 1	2.8741 - 1	2.3462 - 1
41200	41282	216.650	-56.500	1.7702	1.7471	2.8466	2.3237
41400	41482	216.650	-56.500	1.7533	1.7304	2.8193	2.3015
41600	41683	216.650	-56.500	1.7365	1.7138	2.7924	2.2795
41800	41884	216.650	-56.500	1.7199	1.6974	2.7657	2.2577
42000	42085	216.650	-56.500	1.7035	1.6812	2.7392	2.2361
42200	42286	216.650	-56.500	1.6872	1.6651	2.7130	2.2147
42400	42486	216.650	-56.500	1.6710	1.6492	2.6870	2.1935
42600	42687	216.650	-56.500	1.6550	1.6334	2.6613	2.1725
42800	42888	216.650	-56.500	1.6392	1.6178	2.6359	2.1517

Table 2-2: Geometric Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
Z (ft)	H (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
31000	30954	226.824	-46.326	2.8805 + 2	2.8428 - 1	4.4241 - 1	3.6115 - 1
31100	31054	226.626	-46.524	2.8673	2.8296	4.4077	3.5981
31200	31153	226.429	-46.721	2.8542	2.8169	4.3914	3.5848
31300	31253	226.231	-46.919	2.8412	2.8040	4.3751	3.5715
31400	31353	226.034	-47.116	2.8281	2.7912	4.3589	3.5583
31500	31452	225.836	-47.314	2.8152	2.7784	4.3427	3.5450
31600	31552	225.639	-47.511	2.8023	2.7656	4.3265	3.5319
31700	31652	225.441	-47.709	2.7894	2.7529	4.3105	3.5187
31800	31752	225.244	-47.906	2.7766	2.7403	4.2944	3.5056
31900	31851	225.046	-48.104	2.7638	2.7277	4.2794	3.4926
32000	31951	224.849	-48.301	2.7511 + 2	2.7151 - 1	4.2624 - 1	3.4795 - 1
32100	32051	224.651	-48.499	2.7384	2.7026	4.2465	3.4666
32200	32150	224.454	-48.696	2.7258	2.6901	4.2307	3.4536
32300	32250	224.256	-48.894	2.7132	2.6777	4.2148	3.4407
32400	32350	224.059	-49.091	2.7006	2.6653	4.1991	3.4278
32500	32449	223.861	-49.289	2.6882	2.6530	4.1833	3.4150
32600	32549	223.664	-49.486	2.6757	2.6407	4.1677	3.4022
32700	32649	223.466	-49.684	2.6633	2.6285	4.1520	3.3894
32800	32748	223.269	-49.881	2.6510	2.6163	4.1364	3.3767
32900	32848	223.071	-50.079	2.6387	2.6042	4.1209	3.3640
33000	32948	222.874	-50.276	2.6264 + 2	2.5921 - 1	4.1054 - 1	3.3513 - 1
33100	33048	222.676	-50.474	2.6142	2.5800	4.0899	3.3387
33200	33147	222.479	-50.671	2.6020	2.5680	4.0745	3.3261
33300	33247	222.281	-50.869	2.5899	2.5561	4.0591	3.3136
33400	33347	222.084	-51.066	2.5779	2.5441	4.0438	3.3010
33500	33446	221.886	-51.264	2.5658	2.5323	4.0285	3.2886
33600	33546	221.689	-51.461	2.5538	2.5205	4.0133	3.2761
33700	33646	221.491	-51.659	2.5419	2.5087	3.9981	3.2637
33800	33745	221.294	-51.856	2.5300	2.4969	3.9829	3.2514
33900	33845	221.096	-52.054	2.5182	2.4852	3.9678	3.2390
34000	33945	220.899	-52.251	2.5064 + 2	2.4736 - 1	3.9528 - 1	3.2267 - 1
34100	34044	220.701	-52.449	2.4946	2.4620	3.9377	3.2145
34200	34144	220.504	-52.646	2.4829	2.4504	3.9228	3.2023
34300	34244	220.306	-52.844	2.4713	2.4389	3.9078	3.1901
34400	34343	220.109	-53.041	2.4596	2.4275	3.8930	3.1779
34500	34443	219.911	-53.239	2.4481	2.4160	3.8781	3.1658
34600	34543	219.714	-53.436	2.4365	2.4047	3.8633	3.1537
34700	34642	219.516	-53.634	2.4250	2.3933	3.8486	3.1417
34800	34742	219.319	-53.831	2.4136	2.3820	3.8339	3.1297
34900	34842	219.122	-54.028	2.4022	2.3708	3.8192	3.1177
35000	34941	218.924	-54.226	2.3908 + 2	2.3596 - 1	3.8046 - 1	3.1058 - 1
35200	35141	218.529	-54.621	2.3683	2.3373	3.7754	3.0820
35400	35340	218.134	-55.016	2.3459	2.3152	3.7465	3.0584
35600	35539	217.739	-55.411	2.3236	2.2932	3.7177	3.0349
35800	35739	217.344	-55.806	2.3016	2.2715	3.6891	3.0115
36000	35938	216.950	-56.200	2.2797	2.2498	3.6607	2.9883
36200	36137	216.650	-56.500	2.2579	2.2284	3.6308	2.9639
36400	36337	216.650	-56.500	2.2364	2.2072	3.5962	2.9356
36600	36536	216.650	-56.500	2.2151	2.1861	3.5619	2.9077
36800	36735	216.650	-56.500	2.1940	2.1653	3.5279	2.8799
37000	36934	216.650	-56.500	2.1731 + 2	2.1446 - 1	3.4943 - 1	2.8525 - 1
37200	37134	216.650	-56.500	2.1523	2.1242	3.4610	2.8253
37400	37333	216.650	-56.500	2.1318	2.1039	3.4280	2.7984
37600	37532	216.650	-56.500	2.1115	2.0839	3.3953	2.7717
37800	37732	216.650	-56.500	2.0914	2.0640	3.3630	2.7453
38000	37931	216.650	-56.500	2.0714	2.0443	3.3309	2.7191
38200	38130	216.650	-56.500	2.0517	2.0249	3.2992	2.6932
38400	38329	216.650	-56.500	2.0321	2.0056	3.2677	2.6675
38600	38529	216.650	-56.500	2.0128	1.9864	3.2366	2.6421
38800	38728	216.650	-56.500	1.9936	1.9675	3.2057	2.6169
39000	38927	216.650	-56.500	1.9746 + 2	1.9488 - 1	3.1752 - 1	2.5920 - 1
39200	39126	216.650	-56.500	1.9558	1.9302	3.1449	2.5673
39400	39326	216.650	-56.500	1.9371	1.9118	3.1149	2.5428
39600	39525	216.650	-56.500	1.9187	1.8936	3.0852	2.5186
39800	39724	216.650	-56.500	1.9004	1.8755	3.0558	2.4946
40000	39923	216.650	-56.500	1.8823	1.8576	3.0267	2.4708
40200	40123	216.650	-56.500	1.8643	1.8399	2.9979	2.4472
40400	40322	216.650	-56.500	1.8466	1.8224	2.9693	2.4239
40600	40521	216.650	-56.500	1.8290	1.8050	2.9410	2.4008
40800	40720	216.650	-56.500	1.8115	1.7878	2.9130	2.3779
41000	40920	216.650	-56.500	1.7943 + 2	1.7708 - 1	2.8852 - 1	2.3553 - 1
41200	41119	216.650	-56.500	1.7772	1.7539	2.8577	2.3328
41400	41318	216.650	-56.500	1.7602	1.7372	2.8305	2.3106
41600	41517	216.650	-56.500	1.7435	1.7207	2.8035	2.2886
41800	41716	216.650	-56.500	1.7268	1.7043	2.7768	2.2668
42000	41916	216.650	-56.500	1.7104	1.6880	2.7503	2.2452
42200	42115	216.650	-56.500	1.6941	1.6719	2.7241	2.2238
42400	42314	216.650	-56.500	1.6779	1.6560	2.6982	2.2026
42600	42513	216.650	-56.500	1.6620	1.6402	2.6725	2.1816
42800	42712	216.650	-56.500	1.6461	1.6246	2.6470	2.1608

Table 2-2: Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
43000	43089	216.650	-56.500	1.6235 + 2	1.6023 - 1	2.6107 - 1	2.1312 - 1
43200	43290	216.650	-56.500	1.6080	1.5870	2.5857	2.1108
43400	43491	216.650	-56.500	1.5926	1.5718	2.5610	2.0906
43600	43691	216.650	-56.500	1.5774	1.5567	2.5365	2.0706
43800	43892	216.650	-56.500	1.5623	1.5418	2.5122	2.0508
44000	44093	216.650	-56.500	1.5473	1.5271	2.4882	2.0311
44200	44294	216.650	-56.500	1.5325	1.5125	2.4644	2.0117
44400	44495	216.650	-56.500	1.5179	1.4980	2.4408	1.9925
44600	44696	216.650	-56.500	1.5033	1.4837	2.4174	1.9734
44800	44896	216.650	-56.500	1.4890	1.4695	2.3943	1.9545
45000	45097	216.650	-56.500	1.4747 + 2	1.4554 - 1	2.3714 - 1	1.9358 - 1
45200	45298	216.650	-56.500	1.4606	1.4415	2.3487	1.9173
45400	45499	216.650	-56.500	1.4466	1.4277	2.3262	1.8990
45600	45700	216.650	-56.500	1.4328	1.4141	2.3040	1.8808
45800	45901	216.650	-56.500	1.4191	1.4005	2.2819	1.8628
46000	46102	216.650	-56.500	1.4055	1.3871	2.2601	1.8450
46200	46303	216.650	-56.500	1.3921	1.3739	2.2385	1.8273
46400	46503	216.650	-56.500	1.3788	1.3607	2.2171	1.8099
46600	46704	216.650	-56.500	1.3656	1.3477	2.1959	1.7925
46800	46905	216.650	-56.500	1.3525	1.3348	2.1749	1.7754
47000	47106	216.650	-56.500	1.3396 + 2	1.3220 - 1	2.1541 - 1	1.7584 -
47200	47307	216.650	-56.500	1.3267	1.3094	2.1334	1.7416
47400	47508	216.650	-56.500	1.3140	1.2969	2.1130	1.7249
47600	47709	216.650	-56.500	1.3015	1.2845	2.0928	1.7084
47800	47910	216.650	-56.500	1.2890	1.2722	2.0728	1.6921
48000	48111	216.650	-56.500	1.2767	1.2600	2.0530	1.6759
48200	48312	216.650	-56.500	1.2645	1.2479	2.0333	1.6599
48400	48513	216.650	-56.500	1.2524	1.2360	2.0139	1.6440
48600	48714	216.650	-56.500	1.2404	1.2242	1.9946	1.6283
48800	48914	216.650	-56.500	1.2285	1.2125	1.9755	1.6127
49000	49115	216.650	-56.500	1.2168 + 2	1.2009 - 1	1.9566 - 1	1.5972 - 1
49200	49316	216.650	-56.500	1.2051	1.1894	1.9379	1.5820
49400	49517	216.650	-56.500	1.1936	1.1780	1.9194	1.5668
49600	49718	216.650	-56.500	1.1822	1.1667	1.9010	1.5518
49800	49919	216.650	-56.500	1.1709	1.1556	1.8828	1.5370
50000	50120	216.650	-56.500	1.1597	1.1445	1.8648	1.5223
50200	50321	216.650	-56.500	1.1486	1.1336	1.8470	1.5077
50400	50522	216.650	-56.500	1.1376	1.1227	1.8293	1.4933
50600	50723	216.650	-56.500	1.1267	1.1120	1.8118	1.4790
50800	50924	216.650	-56.500	1.1159	1.1013	1.7945	1.4649
51000	51125	216.650	-56.500	1.1053 + 2	1.0908 - 1	1.7773 - 1	1.4509 - 1
51200	51326	216.650	-56.500	1.0947	1.0804	1.7603	1.4370
51400	51527	216.650	-56.500	1.0842	1.0700	1.7435	1.4232
51600	51728	216.650	-56.500	1.0738	1.0598	1.7268	1.4096
51800	51929	216.650	-56.500	1.0636	1.0497	1.7103	1.3961
52000	52130	216.650	-56.500	1.0534	1.0396	1.6939	1.3828
52200	52331	216.650	-56.500	1.0433	1.0297	1.6777	1.3695
52400	52532	216.650	-56.500	1.0333	1.0198	1.6616	1.3564
52600	52733	216.650	-56.500	1.0234	1.0101	1.6457	1.3435
52800	52934	216.650	-56.500	1.0137	1.0004	1.6300	1.3306
53000	53135	216.650	-56.500	1.0040 + 2	9.9087 - 2	1.6144 - 1	1.3179 - 1
53200	53336	216.650	-56.500	9.9439 + 1	9.8139	1.5990	1.3053
53400	53537	216.650	-56.500	9.8488	9.7200	1.5837	1.2928
53600	53738	216.650	-56.500	9.7546	9.6270	1.5685	1.2804
53800	53939	216.650	-56.500	9.6613	9.5349	1.5535	1.2682
54000	54140	216.650	-56.500	9.5688	9.4437	1.5387	1.2560
54200	54341	216.650	-56.500	9.4773	9.3534	1.5239	1.2440
54400	54542	216.650	-56.500	9.3866	9.2639	1.5094	1.2321
54600	54743	216.650	-56.500	9.2968	9.1753	1.4949	1.2203
54800	54944	216.650	-56.500	9.2079	9.0875	1.4806	1.2087
55000	55145	216.650	-56.500	9.1198 + 1	9.0005 - 2	1.4664 - 1	1.1971 - 1
55200	55346	216.650	-56.500	9.0326	8.9144	1.4524	1.1856
55400	55548	216.650	-56.500	8.9461	8.8292	1.4385	1.1743
55600	55749	216.650	-56.500	8.8606	8.7447	1.4248	1.1631
55800	55950	216.650	-56.500	8.7758	8.6610	1.4111	1.1519
56000	56151	216.650	-56.500	8.6918	8.5782	1.3976	1.1409
56200	56352	216.650	-56.500	8.6087	8.4961	1.3843	1.1300
56400	56553	216.650	-56.500	8.5263	8.4148	1.3710	1.1192
56600	56754	216.650	-56.500	8.4448	8.3343	1.3579	1.1085
56800	56955	216.650	-56.500	8.3640	8.2546	1.3449	1.0979
57000	57156	216.650	-56.500	8.2840 + 1	8.1756 - 2	1.3320 - 1	1.0874 - 1
57200	57357	216.650	-56.500	8.2047	8.0974	1.3193	1.0770
57400	57558	216.650	-56.500	8.1262	8.0199	1.3067	1.0667
57600	57760	216.650	-56.500	8.0485	7.9432	1.2942	1.0565
57800	57961	216.650	-56.500	7.9715	7.8672	1.2818	1.0464
58000	58162	216.650	-56.500	7.8952	7.7920	1.2695	1.0364
58200	58363	216.650	-56.500	7.8197	7.7174	1.2574	1.0264
58400	58564	216.650	-56.500	7.7449	7.6436	1.2454	1.0166
58600	58765	216.650	-56.500	7.6708	7.5705	1.2335	1.0069
58800	58966	216.650	-56.500	7.5974	7.4980	1.2217	9.9727 - 2

Table 2-2: Geometric Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
Z (ft)	H (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
43000	42912	216.650	-56.500	1.6304 + 2	1.6091 - 1	2.6218 - 1	2.1402 - 1
43200	43111	216.650	-56.500	1.6149	1.5938	2.5968	2.1198
43400	43310	216.650	-56.500	1.5995	1.5786	2.5721	2.0996
43600	43509	216.650	-56.500	1.5843	1.5636	2.5476	2.0796
43800	43708	216.650	-56.500	1.5692	1.5487	2.5233	2.0598
44000	43907	216.650	-56.500	1.5542	1.5339	2.4993	2.0402
44200	44107	216.650	-56.500	1.5394	1.5193	2.4754	2.0208
44400	44306	216.650	-56.500	1.5248	1.5048	2.4519	2.0015
44600	44505	216.650	-56.500	1.5102	1.4905	2.4285	1.9825
44800	44704	216.650	-56.500	1.4959	1.4763	2.4054	1.9636
45000	44903	216.650	-56.500	1.4816 + 2	1.4622 - 1	2.3825 - 1	1.9449 - 1
45200	45102	216.650	-56.500	1.4675	1.4483	2.3598	1.9263
45400	45301	216.650	-56.500	1.4535	1.4345	2.3373	1.9080
45600	45501	216.650	-56.500	1.4397	1.4208	2.3150	1.8898
45800	45700	216.650	-56.500	1.4259	1.4073	2.2930	1.8718
46000	45899	216.650	-56.500	1.4124	1.3939	2.2711	1.8540
46200	46098	216.650	-56.500	1.3989	1.3806	2.2495	1.8363
46400	46297	216.650	-56.500	1.3856	1.3675	2.2281	1.8188
46600	46496	216.650	-56.500	1.3724	1.3544	2.2069	1.8015
46800	46695	216.650	-56.500	1.3593	1.3415	2.1858	1.7844
47000	46894	216.650	-56.500	1.3464 + 2	1.3288 - 1	2.1650 - 1	1.7674 - 1
47200	47093	216.650	-56.500	1.3336	1.3161	2.1444	1.7505
47400	47293	216.650	-56.500	1.3209	1.3036	2.1240	1.7339
47600	47492	216.650	-56.500	1.3083	1.2912	2.1038	1.7173
47800	47691	216.650	-56.500	1.2958	1.2789	2.0837	1.7010
48000	47890	216.650	-56.500	1.2835	1.2667	2.0639	1.6848
48200	48089	216.650	-56.500	1.2712	1.2546	2.0442	1.6687
48400	48288	216.650	-56.500	1.2591	1.2427	2.0248	1.6529
48600	48487	216.650	-56.500	1.2472	1.2308	2.0055	1.6371
48800	48686	216.650	-56.500	1.2353	1.2191	1.9864	1.6215
49000	48885	216.650	-56.500	1.2235 + 2	1.2075 - 1	1.9675 - 1	1.6061 - 1
49200	49084	216.650	-56.500	1.2119	1.1960	1.9487	1.5908
49400	49283	216.650	-56.500	1.2003	1.1846	1.9302	1.5756
49600	49482	216.650	-56.500	1.1889	1.1733	1.9118	1.5606
49800	49681	216.650	-56.500	1.1776	1.1622	1.8936	1.5458
50000	49880	216.650	-56.500	1.1664	1.1511	1.8756	1.5311
50200	50079	216.650	-56.500	1.1553	1.1401	1.8577	1.5165
50400	50278	216.650	-56.500	1.1443	1.1293	1.8400	1.5021
50600	50478	216.650	-56.500	1.1334	1.1185	1.8225	1.4878
50800	50677	216.650	-56.500	1.1226	1.1079	1.8051	1.4636
51000	50876	216.650	-56.500	1.1119 + 2	1.0973 - 1	1.7880 - 1	1.4596 - 1
51200	51075	216.650	-56.500	1.1013	1.0869	1.7709	1.4457
51400	51274	216.650	-56.500	1.0908	1.0765	1.7541	1.4319
51600	51473	216.650	-56.500	1.0804	1.0663	1.7374	1.4183
51800	51672	216.650	-56.500	1.0701	1.0561	1.7208	1.4048
52000	51871	216.650	-56.500	1.0600	1.0461	1.7045	1.3914
52200	52070	216.650	-56.500	1.0499	1.0361	1.6882	1.3782
52400	52269	216.650	-56.500	1.0399	1.0263	1.6722	1.3650
52600	52468	216.650	-56.500	1.0300	1.0165	1.6562	1.3520
52800	52667	216.650	-56.500	1.0202	1.0068	1.6405	1.3392
53000	52866	216.650	-56.500	1.0105 + 2	9.9729 - 2	1.6249 - 1	1.3264 - 1
53200	53065	216.650	-56.500	1.0008	9.8779	1.6094	1.3138
53400	53264	216.650	-56.500	9.9135 + 1	9.7839	1.5941	1.3013
53600	53463	216.650	-56.500	9.8192	9.6908	1.5789	1.2889
53800	53662	216.650	-56.500	9.7257	9.5985	1.5639	1.2766
54000	53861	216.650	-56.500	9.6332	9.5072	1.5490	1.2645
54200	54059	216.650	-56.500	9.5415	9.4167	1.5343	1.2525
54400	54258	216.650	-56.500	9.4507	9.3271	1.5197	1.2405
54600	54457	216.650	-56.500	9.3607	9.2383	1.5052	1.2287
54800	54656	216.650	-56.500	9.2716	9.1504	1.4909	1.2170
55000	54855	216.650	-56.500	9.1834 + 1	9.0633 - 2	1.4767 - 1	1.2055 - 1
55200	55054	216.650	-56.500	9.0960	8.9771	1.4626	1.1940
55400	55253	216.650	-56.500	9.0095	8.8916	1.4487	1.1826
55600	55452	216.650	-56.500	8.9237	8.8070	1.4349	1.1714
55800	55651	216.650	-56.500	8.8388	8.7232	1.4213	1.1602
56000	55850	216.650	-56.500	8.7547	8.6402	1.4077	1.1492
56200	56049	216.650	-56.500	8.6714	8.5580	1.3943	1.1382
56400	56248	216.650	-56.500	8.5889	8.4766	1.3811	1.1274
56600	56447	216.650	-56.500	8.5071	8.3959	1.3679	1.1167
56800	56646	216.650	-56.500	8.4262	8.3160	1.3549	1.1061
57000	56845	216.650	-56.500	8.3460 + 1	8.2369 - 2	1.3420 - 1	1.0955 - 1
57200	57044	216.650	-56.500	8.2666	8.1585	1.3293	1.0851
57400	57242	216.650	-56.500	8.1880	8.0809	1.3166	1.0748
57600	57441	216.650	-56.500	8.1101	8.0040	1.3041	1.0646
57800	57640	216.650	-56.500	8.0329	7.9278	1.2917	1.0544
58000	57839	216.650	-56.500	7.9565	7.8524	1.2794	1.0444
58200	58038	216.650	-56.500	7.8808	7.7777	1.2672	1.0345
58400	58237	216.650	-56.500	7.8058	7.7037	1.2552	1.0246
58600	58436	216.650	-56.500	7.7315	7.6304	1.2432	1.0149
58800	58635	216.650	-56.500	7.6580	7.5578	1.2314	1.0052

Table 2-2 Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m³)	ρ/ρ_0
59000	59167	216.650	-56.500	7.5247 + 1	7.4263 - 2	1.2100 - 1	9.8773 - 2
59200	59369	216.650	-56.500	7.4527	7.3553	1.1984	9.7828
59400	59570	216.650	-56.500	7.3814	7.2849	1.1869	9.6892
59600	59771	216.650	-56.500	7.3108	7.2152	1.1756	9.5965
59800	59972	216.650	-56.500	7.2409	7.1462	1.1643	9.5047
60000	60173	216.650	-56.500	7.1716	7.0778	1.1532	9.4137
60200	60374	216.650	-56.500	7.1030	7.0101	1.1422	9.3237
60400	60575	216.650	-56.500	7.0350	6.9430	1.1312	9.2345
60600	60777	216.650	-56.500	6.9677	6.8766	1.1204	9.1462
60800	60978	216.650	-56.500	6.9011	6.8108	1.1097	9.0587
61000	61179	216.650	-56.500	6.8351 + 1	6.7457 - 2	1.0991 - 1	8.9720 - 2
61200	61380	216.650	-56.500	6.7697	6.6811	1.0886	8.8862
61400	61581	216.650	-56.500	6.7049	6.6172	1.0781	8.8011
61600	61782	216.650	-56.500	6.6408	6.5539	1.0678	8.7170
61800	61984	216.650	-56.500	6.5772	6.4912	1.0576	8.6336
62000	62185	216.650	-56.500	6.5143	6.4291	1.0475	8.5510
62200	62386	216.650	-56.500	6.4520	6.3676	1.0375	8.4692
62400	62587	216.650	-56.500	6.3903	6.3067	1.0275	8.3881
62600	62788	216.650	-56.500	6.3291	6.2464	1.0177	8.3079
62800	62990	216.650	-56.500	6.2686	6.1866	1.0080	8.2284
63000	63191	216.650	-56.500	6.2086 + 1	6.1274 - 2	9.9834 - 2	8.1497 - 2
63200	63392	216.650	-56.500	6.1492	6.0688	9.8879	8.0717
63400	63593	216.650	-56.500	6.0904	6.0107	9.7933	7.9945
63600	63795	216.650	-56.500	6.0321	5.9532	9.6996	7.9180
63800	63996	216.650	-56.500	5.9744	5.8963	9.6068	7.8423
64000	64197	216.650	-56.500	5.9173	5.8399	9.5149	7.7673
64200	64398	216.650	-56.500	5.8607	5.7840	9.4239	7.6930
64400	64599	216.650	-56.500	5.8046	5.7287	9.3337	7.6194
64600	64801	216.650	-56.500	5.7491	5.6739	9.2444	7.5465
64800	65002	216.650	-56.500	5.6941	5.6196	9.1560	7.4743
65000	65203	216.650	-56.500	5.6396 + 1	5.5658 - 2	9.0684 - 2	7.4028 - 2
65200	65404	216.650	-56.500	5.5856	5.5126	8.9816	7.3319
65400	65606	216.650	-56.500	5.5322	5.4599	8.8957	7.2618
65600	65807	216.650	-56.500	5.4793	5.4076	8.8106	7.1923
65800	66008	216.706	-56.444	5.4269	5.3559	8.7241	7.1217
66000	66210	216.767	-56.383	5.3750	5.3047	8.6382	7.0516
66200	66411	216.828	-56.322	5.3236	5.2540	8.5532	6.9822
66400	66612	216.889	-56.261	5.2727	5.2037	8.4691	6.9136
66600	66813	216.950	-56.200	5.2223	5.1540	8.3858	6.8456
66800	67015	217.011	-56.139	5.1724	5.1048	8.3034	6.7783
67000	67216	217.072	-56.078	5.1230 + 1	5.0560 - 2	8.2218 - 2	6.7117 - 2
67200	67417	217.133	-56.017	5.0741	5.0078	8.1410	6.6457
67400	67619	217.194	-55.956	5.0257	4.9600	8.0611	6.5805
67600	67820	217.255	-55.895	4.9777	4.9127	7.9819	6.5158
67800	68021	217.316	-55.834	4.9303	4.8658	7.9035	6.4519
68000	68222	217.377	-55.773	4.8833	4.8194	7.8260	6.3886
68200	68424	217.438	-55.712	4.8367	4.7734	7.7492	6.3259
68400	68625	217.499	-55.651	4.7906	4.7279	7.6732	6.2638
68600	68826	217.559	-55.591	4.7450	4.6829	7.5980	6.2024
68800	69028	217.620	-55.530	4.6998	4.6383	7.5235	6.1416
69000	69229	217.681	-55.469	4.6550 + 1	4.5941 - 2	7.4497 - 2	6.0814 - 2
69200	69430	217.742	-55.408	4.6107	4.5504	7.3767	6.0218
69400	69632	217.803	-55.347	4.5668	4.5071	7.3045	5.9629
69600	69833	217.864	-55.286	4.5233	4.4642	7.2330	5.9045
69800	70034	217.925	-55.225	4.4803	4.4217	7.1622	5.8467
70000	70236	217.986	-55.164	4.4377	4.3797	7.0921	5.7894
70200	70437	218.047	-55.103	4.3955	4.3380	7.0227	5.7328
70400	70638	218.108	-55.042	4.3537	4.2968	6.9540	5.6767
70600	70840	218.169	-54.981	4.3124	4.2560	6.8860	5.6212
70800	71041	218.230	-54.920	4.2714	4.2156	6.8187	5.5663
71000	71243	218.291	-54.859	4.2308 + 1	4.1755 - 2	6.7520 - 2	5.5119 - 2
71200	71444	218.352	-54.798	4.1907	4.1359	6.6861	5.4580
71400	71645	218.413	-54.737	4.1509	4.0966	6.6208	5.4047
71600	71847	218.474	-54.676	4.1115	4.0578	6.5561	5.3519
71800	72048	218.535	-54.615	4.0725	4.0193	6.4921	5.2997
72000	72249	218.596	-54.554	4.0339	3.9811	6.4288	5.2480
72200	72451	218.657	-54.493	3.9957	3.9434	6.3660	5.1968
72400	72652	218.718	-54.432	3.9578	3.9060	6.3039	5.1461
72600	72854	218.779	-54.371	3.9203	3.8690	6.2425	5.0959
72800	73055	218.840	-54.310	3.8831	3.8324	6.1816	5.0462
73000	73256	218.901	-54.249	3.8464 + 1	3.7961 - 2	6.1214 - 2	4.9970 - 2
73200	73458	218.962	-54.188	3.[illegible]100	3.7601	6.0617	4.9483
73400	73659	219.023	-54.127	3.7739	3.7245	6.0027	4.9001
73600	73861	219.083	-54.067	3.7382	3.6893	5.9442	4.8524
73800	74062	219.144	-54.006	3.7028	3.6544	5.8864	4.8052
74000	74264	219.205	-53.945	3.6678	3.6198	5.8291	4.7584
74200	74465	219.266	-53.884	3.6331	3.5856	5.7724	4.7121
74400	74666	219.327	-53.823	3.5988	3.5517	5.7162	4.6663
74600	74868	219.388	-53.762	3.5648	3.5182	5.6606	4.6209
74800	75069	219.449	-53.701	3.5311	3.4849	5.6056	4.5760

Table 2-2: Geometric Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
Z (ft)	H (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
59000	58834	216.650	-56.500	7.5851 + 1	7.4859 - 2	1.2197 - 1	9.9566 - 2
59200	59032	216.650	-56.500	7.5130	7.4147	1.2081	9.8618
59400	59231	216.650	-56.500	7.4415	7.3442	1.1966	9.7680
59600	59430	216.650	-56.500	7.3707	7.2743	1.1852	9.6751
59800	59629	216.650	-56.500	7.3006	7.2051	1.1739	9.5831
60000	59828	216.650	-56.500	7.2312	7.1366	1.1628	9.4919
60200	60027	216.650	-56.500	7.1624	7.0687	1.1517	9.4016
60400	60226	216.650	-56.500	7.0942	7.0015	1.1407	9.3122
60600	60424	216.650	-56.500	7.0268	6.9349	1.1299	9.2236
60800	60623	216.650	-56.500	6.9599	6.8689	1.1191	9.1359
61000	60822	216.650	-56.500	6.8937 + 1	6.8036 - 2	1.1085 - 1	9.0490 - 2
61200	61021	216.650	-56.500	6.8282	6.7389	1.0980	8.9629
61400	61220	216.650	-56.500	6.7632	6.6748	1.0875	8.8777
61600	61419	216.650	-56.500	6.6989	6.6113	1.0772	8.7933
61800	61617	216.650	-56.500	6.6352	6.5484	1.0669	8.7096
62000	61816	216.650	-56.500	6.5721	6.4861	1.0568	8.6268
62200	62015	216.650	-56.500	6.5096	6.4245	1.0467	8.5448
62400	62214	216.650	-56.500	6.4477	6.3634	1.0368	8.4635
62600	62413	216.650	-56.500	6.3864	6.3028	1.0269	8.3810
62800	62611	216.650	-56.500	6.3256	6.2429	1.0172	8.3033
63000	62810	216.650	-56.500	6.2655 + 1	6.1835 - 2	1.0075 - 1	8.2243 - 2
63200	63009	216.650	-56.500	6.2059	6.1247	9.9790 - 2	8.1461
63400	63208	216.650	-56.500	6.1469	6.0665	9.8841	8.0687
63600	63407	216.650	-56.500	6.0884	6.0088	9.7901	7.9919
63800	63605	216.650	-56.500	6.0305	5.9517	9.6970	7.9159
64000	63804	216.650	-56.500	5.9732	5.8951	9.6048	7.8407
64200	64003	216.650	-56.500	5.9164	5.8390	9.5135	7.7661
64400	64202	216.650	-56.500	5.8601	5.7835	9.4231	7.6923
64600	64401	216.650	-56.500	5.8044	5.7285	9.3335	7.6191
64800	64599	216.650	-56.500	5.7492	5.6741	9.2447	7.5467
65000	64798	216.650	-56.500	5.6946 + 1	5.6201 - 2	9.1568 - 2	7.4750 - 2
65200	64997	216.650	-56.500	5.6404	5.5667	9.0698	7.4039
65400	65196	216.650	-56.500	5.5868	5.5137	8.9835	7.3335
65600	65394	216.650	-56.500	5.5337	5.4613	8.8981	7.2638
65800	65593	216.650	-56.500	5.4811	5.4094	8.8135	7.1947
66000	65792	216.703	-56.447	5.4290	5.3580	8.7276	7.1246
66200	65991	216.764	-56.386	5.3774	5.3071	8.6423	7.0549
66400	66189	216.824	-56.326	5.3263	5.2567	8.5578	6.9859
66600	66388	216.885	-56.265	5.2757	5.2067	8.4741	6.9176
66800	66587	216.945	-56.205	5.2256	5.1573	8.3913	6.8500
67000	66785	217.006	-56.144	5.1760 + 1	5.1083 - 2	8.3094 - 2	6.7831 - 2
67200	66984	217.067	-56.083	5.1269	5.0599	8.2282	6.7169
67400	67183	217.127	-56.023	5.0783	5.0119	8.1479	6.6513
67600	67382	217.188	-55.962	5.0301	4.9643	8.0684	6.5864
67800	67580	217.248	-55.902	4.9824	4.9173	7.9896	6.5222
68000	67779	217.309	-55.841	4.9352	4.8707	7.9117	6.4585
68200	67978	217.369	-55.781	4.8885	4.8245	7.8346	6.3956
68400	68176	217.430	-55.720	4.8421	4.7788	7.7582	6.3332
68600	68375	217.491	-55.659	4.7963	4.7336	7.6826	6.2715
68800	68574	217.551	-55.599	4.7509	4.6888	7.6078	6.2104
69000	68772	217.612	-55.538	4.7059 + 1	4.6444 - 2	7.5337 - 2	6.1499 - 2
69200	68971	217.672	-55.478	4.6614	4.6004	7.4603	6.0900
69400	69170	217.733	-55.417	4.6173	4.5569	7.3877	6.0308
69600	69368	217.793	-55.357	4.5737	4.5139	7.3158	5.9721
69800	69567	217.854	-55.296	4.5304	4.4712	7.2446	5.9140
70000	69766	217.914	-55.236	4.4876	4.4289	7.1742	5.8565
70200	69964	217.975	-55.175	4.4452	4.3871	7.1044	5.7995
70400	70163	218.036	-55.114	4.4032	4.3457	7.0354	5.7432
70600	70362	218.096	-55.054	4.3617	4.3046	6.9670	5.6874
70800	70560	218.157	-54.993	4.3205	4.2640	6.8994	5.6321
71000	70759	218.217	-54.933	4.2797 + 1	4.2238 - 2	6.8324 - 2	5.5774 - 2
71200	70958	218.278	-54.872	4.2394	4.1839	6.7660	5.5233
71400	71156	218.338	-54.812	4.1994	4.1445	6.7004	5.4697
71600	71355	218.399	-54.751	4.1598	4.1054	6.6354	5.4166
71800	71554	218.459	-54.691	4.1206	4.0667	6.5710	5.3641
72000	71752	218.520	-54.630	4.0818	4.0284	6.5073	5.3121
72200	71951	218.581	-54.569	4.0433	3.9904	6.4442	5.2606
72400	72150	218.641	-54.509	4.0053	3.9529	6.3818	5.2096
72600	72348	218.702	-54.448	3.9675	3.9157	6.3200	5.1591
72800	72547	218.762	-54.388	3.9302	3.8788	6.2588	5.1092
73000	72745	218.823	-54.327	3.8932 + 1	3.8423 - 2	6.1982 - 2	5.0597 - 2
73200	72944	218.883	-54.267	3.8566	3.8062	6.1382	5.0107
73400	73143	218.944	-54.206	3.8204	3.7704	6.0788	4.9623
73600	73341	219.004	-54.146	3.7844	3.7350	6.0200	4.9143
73800	73540	219.065	-54.085	3.7489	3.6999	5.9618	4.8667
74000	73738	219.125	-54.025	3.7137	3.6651	5.9041	4.8197
74200	73937	219.186	-53.964	3.6788	3.6307	5.8471	4.7731
74400	74136	219.246	-53.904	3.6443	3.5966	5.7906	4.7270
74600	74334	219.307	-53.843	3.6100	3.5628	5.7346	4.6813
74800	74533	219.367	-53.783	3.5762	3.5294	5.6793	4.6361

Table 2-2: Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
75000	75271	219.510	-53.640	3.4978 + 1	3.4520 - 2	5.5511 - 2	4.5315 - 2
75200	75472	219.571	-53.579	3.4647	3.4194	5.4972	4.4875
75400	75674	219.632	-53.518	3.4320	3.3872	5.4438	4.4439
75600	75875	219.693	-53.457	3.3996	3.3552	5.3909	4.4007
75800	76077	219.754	-53.396	3.3676	3.3235	5.3386	4.3580
76000	76278	219.815	-53.335	3.3358	3.2922	5.2868	4.3157
76200	76479	219.876	-53.274	3.3044	3.2612	5.2355	4.2738
76400	76681	219.937	-53.213	3.2732	3.2304	5.1847	4.2324
76600	76882	219.998	-53.152	3.2424	3.2000	5.1344	4.1913
76800	77084	220.059	-53.091	3.2118	3.1698	5.0846	4.1507
77000	77285	220.120	-53.030	3.1816 + 1	3.1400 - 2	5.0353 - 2	4.1105 - 2
77200	77487	220.181	-52.969	3.1516	3.1104	4.9866	4.0707
77400	77688	220.242	-52.908	3.1220	3.0811	4.9382	4.0312
77600	77890	220.303	-52.847	3.0926	3.0521	4.8904	3.9922
77800	78091	220.364	-52.786	3.0635	3.0234	4.8431	3.9535
78000	78293	220.425	-52.725	3.0347	2.9950	4.7962	3.9153
78200	78494	220.486	-52.664	3.0061	2.9668	4.7498	3.8774
78400	78696	220.547	-52.603	2.9779	2.9389	4.7038	3.8399
78600	78897	220.607	-52.543	2.9499	2.9113	4.6584	3.8027
78800	79099	220.668	-52.482	2.9222	2.8840	4.6133	3.7660
79000	79300	220.729	-52.421	2.8947 + 1	2.8569 - 2	4.5687 - 2	3.7296 - 2
79200	79502	220.790	-52.360	2.8676	2.8301	4.5246	3.6935
79400	79703	220.851	-52.299	2.8406	2.8035	4.4809	3.6579
79600	79905	220.912	-52.238	2.8140	2.7772	4.4376	3.6225
79800	80107	220.973	-52.177	2.7876	2.7511	4.3948	3.5876
80000	80308	221.034	-52.116	2.7614	2.7253	4.3523	3.5529
80200	80510	221.095	-52.055	2.7355	2.6998	4.3103	3.5186
80400	80711	221.156	-51.994	2.7099	2.6745	4.2680	3.4847
80600	80913	221.217	-51.933	2.6845	2.6494	4.2276	3.4511
80800	81114	221.278	-51.872	2.6594	2.6246	4.1868	3.4178
81000	81316	221.339	-51.811	2.6344 + 1	2.6000 - 2	4.1465 - 2	3.3849 - 2
81200	81517	221.400	-51.750	2.6098	2.5757	4.1065	3.3523
81400	81719	221.461	-51.689	2.5853	2.5515	4.0669	3.3200
81600	81921	221.522	-51.628	2.5612	2.5277	4.0278	3.2880
81800	82122	221.583	-51.567	2.5372	2.5040	3.9890	3.2563
82000	82324	221.644	-51.506	2.5135	2.4806	3.9506	3.2250
82200	82525	221.705	-51.445	2.4900	2.4574	3.9126	3.1939
82400	82727	221.766	-51.384	2.4667	2.4344	3.8749	3.1632
82600	82928	221.827	-51.323	2.4436	2.4117	3.8377	3.1328
82800	83130	221.888	-51.262	2.4208	2.3891	3.8008	3.1027
83000	83332	221.949	-51.201	2.3982 + 1	2.3668 - 2	3.7642 - 2	3.0728 - 2
83200	83533	222.010	-51.140	2.3758	2.3447	3.7281	3.0433
83400	83735	222.071	-51.079	2.3536	2.3228	3.6922	3.0141
83600	83936	222.131	-51.019	2.3316	2.3011	3.6568	2.9851
83800	84138	222.192	-50.958	2.3099	2.2797	3.6217	2.9565
84000	84340	222.253	-50.897	2.2883	2.2584	3.5869	2.9281
84200	84541	222.314	-50.836	2.2670	2.2374	3.5525	2.9000
84400	84743	222.375	-50.775	2.2459	2.2165	3.5184	2.8722
84600	84945	222.436	-50.714	2.2249	2.1958	3.4846	2.8446
84800	85146	222.497	-50.653	2.2042	2.1754	3.4512	2.8173
85000	85348	222.558	-50.592	2.1837 + 1	2.1551 - 2	3.4181 - 2	2.7903 - 2
85200	85550	222.619	-50.531	2.1633	2.1350	3.3854	2.7636
85400	85751	222.680	-50.470	2.1432	2.1152	3.3530	2.7371
85600	85953	222.741	-50.409	2.1232	2.0955	3.3208	2.7109
85800	86154	222.802	-50.348	2.1035	2.0760	3.2890	2.6849
86000	86356	222.863	-50.287	2.0839	2.0567	3.2575	2.6592
86200	86558	222.924	-50.226	2.0645	2.0375	3.2264	2.6338
86400	86759	222.985	-50.165	2.0453	2.0186	3.1955	2.6086
86600	86961	223.046	-50.104	2.0263	1.9998	3.1649	2.5836
86800	87163	223.107	-50.043	2.0075	1.9812	3.1347	2.5589
87000	87364	223.168	-49.982	1.9888 + 1	1.9628 - 2	3.1047 - 2	2.5344 - 2
87200	87566	223.229	-49.921	1.9704	1.9446	3.0750	2.5102
87400	87768	223.290	-49.860	1.9521	1.9266	3.0456	2.4862
87600	87970	223.351	-49.799	1.9340	1.9087	3.0165	2.4625
87800	88171	223.412	-49.738	1.9160	1.8910	2.9877	2.4390
88000	88373	223.473	-49.677	1.8982	1.8734	2.9592	2.4157
88200	88575	223.534	-49.616	1.8806	1.8560	2.9310	2.3976
88400	88776	223.595	-49.555	1.8632	1.8388	2.9030	2.3698
88600	88978	223.655	-49.495	1.8459	1.8218	2.8753	2.3472
88800	89180	223.716	-49.434	1.8288	1.8049	2.8479	2.3248
89000	89381	223.777	-49.373	1.8119 + 1	1.7882 - 2	2.8207 - 2	2.3026 - 2
89200	89583	223.838	-49.312	1.7951	1.7716	2.7938	2.2807
89400	89785	223.899	-49.251	1.7785	1.7552	2.7672	2.2590
89600	89987	223.960	-49.190	1.7620	1.7390	2.7409	2.2374
89800	90188	224.021	-49.129	1.7457	1.7229	2.7148	2.2161
90000	90390	224.082	-49.068	1.7295	1.7069	2.6889	2.1950
90200	90592	224.143	-49.007	1.7135	1.6911	2.6633	2.1741
90400	90794	224.204	-48.946	1.6977	1.6755	2.6380	2.1534
90600	90995	224.265	-48.885	1.6820	1.6600	2.6129	2.1330
90800	91197	224.326	-48.824	1.6665	1.6447	2.5880	2.1127

Table 2-2:

Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
91000	91399	224.387	-48.763	1.6511 + 1	1.6295 - 2	2.5634 - 2	2.0926 - 2
91200	91601	224.448	-48.702	1.6358	1.6144	2.5390	2.0727
91400	91802	224.509	-48.641	1.6207	1.5995	2.5149	2.0530
91600	92004	224.570	-48.580	1.6057	1.5847	2.4910	2.0335
91800	92206	224.631	-48.519	1.5909	1.5701	2.4674	2.0142
92000	92408	224.692	-48.458	1.5762	1.5556	2.4439	1.9950
92200	92609	224.753	-48.397	1.5617	1.5413	2.4207	1.9761
92400	92811	224.814	-48.336	1.5473	1.5271	2.3977	1.9573
92600	93013	224.875	-48.275	1.5330	1.5130	2.3750	1.9388
92800	93215	224.936	-48.214	1.5189	1.4990	2.3525	1.9204
93000	93417	224.997	-48.153	1.5049 + 1	1.4852 - 2	2.3302 - 2	1.9022 - 2
93200	93618	225.058	-48.092	1.4910	1.4715	2.3081	1.8841
93400	93820	225.119	-48.031	1.4773	1.4580	2.2862	1.8663
93600	94022	225.179	-47.971	1.4637	1.444	2.2645	1.8486
93800	94224	225.240	-47.910	1.4502	1.4313	2.2431	1.8311
94000	94426	225.301	-47.849	1.4369	1.4181	2.2218	1.8137
94200	94627	225.362	-47.788	1.4237	1.4051	2.2008	1.7966
94400	94829	225.423	-47.727	1.4106	1.3921	2.1800	1.7796
94600	95031	225.484	-47.666	1.3976	1.3793	2.1593	1.7627
94800	95233	225.545	-47.605	1.3848	1.3666	2.1389	1.7461
95000	95435	225.606	-47.544	1.3720 + 1	1.3541 - 2	2.1187 - 2	1.7295 - 2
95200	95637	225.667	-47.483	1.3594	1.3416	2.0987	1.7132
95400	95838	225.728	-47.422	1.3469	1.3293	2.0788	1.6970
95600	96040	225.789	-47.361	1.3346	1.3171	2.0592	1.6810
95800	96242	225.850	-47.300	1.3223	1.3050	2.0397	1.6651
96000	96444	225.911	-47.239	1.3102	1.2930	2.0205	1.6493
96200	96646	225.972	-47.178	1.2982	1.2812	2.0014	1.6338
96400	96848	226.033	-47.117	1.2863	1.2694	1.9825	1.6184
96600	97050	226.094	-47.056	1.2745	1.2578	1.9638	1.6031
96800	97251	226.155	-46.995	1.2628	1.2463	1.9452	1.5880
97000	97453	226.216	-46.934	1.2512 + 1	1.2348 - 2	1.9269 - 2	1.5730 - 2
97200	97655	226.277	-46.873	1.2397	1.2235	1.9087	1.5581
97400	97857	226.338	-46.812	1.2284	1.2123	1.8907	1.5435
97600	98059	226.399	-46.751	1.2171	1.2012	1.8729	1.5289
97800	98261	226.460	-46.690	1.2060	1.1902	1.8553	1.5145
98000	98463	226.521	-46.629	1.1949	1.1793	1.8378	1.5002
98200	98665	226.582	-46.568	1.1840	1.1685	1.8205	1.4861
98400	98866	226.643	-46.507	1.1732	1.1578	1.8033	1.4721
98600	99068	226.703	-46.447	1.1624	1.1472	1.7864	1.4583
98800	99270	226.764	-46.386	1.1518	1.1368	1.7696	1.4445
99000	99472	226.825	-46.325	1.1413 + 1	1.1264 - 2	1.7529 - 2	1.4310 - 2
99200	99674	226.886	-46.264	1.1309	1.1161	1.7364	1.4175
99400	99876	226.947	-46.203	1.1205	1.1059	1.7201	1.4042
99600	100078	227.008	-46.142	1.1103	1.0958	1.7039	1.3910
99800	100280	227.069	-46.081	1.1002	1.0858	1.6879	1.3779
100000	100482	227.130	-46.020	1.0901	1.0759	1.6721	1.3650
100200	100684	227.191	-45.959	1.0802	1.0660	1.6564	1.3521
100400	100886	227.252	-45.898	1.0703	1.0563	1.6408	1.3394
100600	101088	227.313	-45.837	1.0605	1.0467	1.6254	1.3269
100800	101290	227.374	-45.776	1.0509	1.0371	1.6102	1.3144
101000	101492	227.435	-45.715	1.0413 + 1	1.0277 - 2	1.5951 - 2	1.3021 - 2
101200	101693	227.496	-45.654	1.0318	1.0183	1.5801	1.2899
101400	101895	227.557	-45.593	1.0224	1.0090	1.5653	1.2778
101600	102097	227.618	-45.532	1.0131	9.9988 - 3	1.5506	1.2658
101800	102299	227.679	-45.471	1.0039	9.9078	1.5361	1.2539
102000	102501	227.740	-45.410	9.9477 + 0	9.8176	1.5217	1.2422
102200	102703	227.801	-45.349	9.8571	9.7282	1.5074	1.2306
102400	102905	227.862	-45.288	9.7674	9.6397	1.4933	1.2190
102600	103107	227.923	-45.227	9.6786	9.5520	1.4793	1.2076
102800	103309	227.984	-45.166	9.5906	9.4651	1.4655	1.1963
103000	103511	228.045	-45.105	9.5034 + 0	9.3791 - 3	1.4518 - 2	1.1851 - 2
103200	103713	228.106	-45.044	9.4170	9.2938	1.4382	1.1740
103400	103915	228.167	-44.983	9.3314	9.2094	1.4247	1.1631
103600	104117	228.227	-44.923	9.2466	9.1257	1.4114	1.1522
103800	104319	228.288	-44.862	9.1627	9.0428	1.3982	1.1414
104000	104521	228.349	-44.801	9.0795	8.9607	1.3852	1.1307
104200	104723	228.410	-44.740	8.9970	8.8794	1.3722	1.1202
104400	104925	228.471	-44.679	8.9154	8.7988	1.3594	1.1097
104600	105127	228.532	-44.618	8.8345	8.7190	1.3467	1.0994
104800	105329	228.593	-44.557	8.7544	8.6399	1.3341	1.0891
105000	105531	228.661	-44.489	8.6750 + 0	8.5615 - 3	1.3217 - 2	1.0789 - 2
105500	106036	229.088	-44.062	8.4799	8.3690	1.2895	1.0527
106000	106542	229.515	-43.635	8.2895	8.1811	1.2582	1.0271
106500	107047	229.942	-43.208	8.1037	7.9978	1.2277	1.0022
107000	107552	230.368	-42.782	7.9225	7.8189	1.1981	9.7801 - 3
107500	108057	230.795	-42.355	7.7456	7.6443	1.1691	9.5441
108000	108562	231.222	-41.928	7.5730	7.4739	1.1410	9.3141
108500	109067	231.648	-41.502	7.4045	7.3077	1.1135	9.0902
109000	109573	232.075	-41.075	7.2401	7.1454	1.0868	8.8720
109500	110078	232.502	-40.648	7.0796	6.9870	1.0608	8.6594

Table 2-2: Geometric Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
Z (ft)	H (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
75000	74731	219.428	-53.722	3.5426 + 1	3.4963 - 2	5.6244 - 2	4.5914 - 2
75200	74930	219.488	-53.662	3.5094	3.4635	5.5701	4.5471
75400	75128	219.549	-53.601	3.4765	3.4310	5.5164	4.5032
75600	75327	219.610	-53.540	3.4439	3.3989	5.4632	4.4598
75800	75525	219.670	-53.480	3.4117	3.3670	5.4105	4.4168
76000	75724	219.731	-53.419	3.3797	3.3355	5.3584	4.3742
76200	75923	219.791	-53.359	3.3481	3.3043	5.3067	4.3320
76400	76121	219.852	-53.298	3.3167	3.2733	5.2556	4.2903
76600	76320	219.912	-53.238	3.2857	3.2427	5.2050	4.2490
76800	76518	219.973	-53.177	3.2549	3.2124	5.1549	4.2081
77000	76717	220.033	-53.117	3.2245 + 1	3.1823 - 2	5.1053 - 2	4.1676 - 2
77200	76915	220.094	-53.056	3.1943	3.1526	5.0561	4.1275
77400	77114	220.154	-52.996	3.1645	3.1231	5.0075	4.0878
77600	77312	220.215	-52.935	3.1349	3.0939	4.9593	4.0484
77800	77511	220.275	-52.875	3.1056	3.0650	4.9117	4.0095
78000	77709	220.336	-52.814	3.0766	3.0364	4.8645	3.9710
78200	77908	220.396	-52.754	3.0479	3.0080	4.8177	3.9328
78400	78106	220.457	-52.693	3.0195	2.9800	4.7714	3.8951
78600	78305	220.517	-52.633	2.9913	2.9522	4.7256	3.8577
78800	78503	220.578	-52.572	2.9634	2.9246	4.6803	3.8206
79000	78702	220.638	-52.512	2.9357 + 1	2.8973 - 2	4.6353 - 2	3.7840 - 2
79200	78900	220.699	-52.451	2.9084	2.8703	4.5909	3.7476
79400	79099	220.759	-52.391	2.8813	2.8436	4.5468	3.7117
79600	79297	220.820	-52.330	2.8544	2.8171	4.5032	3.6761
79800	79496	220.880	-52.270	2.8278	2.7908	4.4601	3.6409
80000	79694	220.941	-52.209	2.8015	2.7649	4.4173	3.6060
80200	79893	221.001	-52.149	2.7754	2.7391	4.3750	3.5714
80400	80091	221.062	-52.088	2.7496	2.7136	4.3331	3.5372
80600	80290	221.122	-52.028	2.7240	2.6884	4.2916	3.5034
80800	80488	221.183	-51.967	2.6987	2.6634	4.2505	3.4698
81000	80687	221.243	-51.907	2.6736 + 1	2.6386 - 2	4.2099 - 2	3.4366 - 2
81200	80885	221.304	-51.846	2.6487	2.6141	4.1696	3.4037
81400	81084	221.364	-51.786	2.6241	2.5898	4.1297	3.3712
81600	81282	221.425	-51.725	2.5997	2.5657	4.0902	3.3390
81800	81480	221.485	-51.665	2.5756	2.5419	4.0511	3.3071
82000	81679	221.546	-51.604	2.5517	2.5183	4.0124	3.2755
82200	81877	221.606	-51.544	2.5280	2.4949	3.9741	3.2442
82400	82076	221.667	-51.483	2.5045	2.4718	3.9362	3.2132
82600	82274	221.727	-51.423	2.4813	2.4488	3.8986	3.1825
82800	82473	221.788	-51.362	2.4583	2.4261	3.8614	3.1521
83000	82671	221.848	-51.302	2.4355 + 1	2.4036 - 2	3.8245 - 2	3.1221 - 2
83200	82869	221.908	-51.242	2.4129	2.3814	3.7880	3.0923
83400	83068	221.969	-51.181	2.3905	2.3593	3.7519	3.0628
83600	83266	222.029	-51.121	2.3684	2.3374	3.7162	3.0336
83800	83465	222.090	-51.060	2.3465	2.3158	3.6807	3.0047
84000	83663	222.150	-51.000	2.3248	2.2943	3.6457	2.9761
84200	83861	222.211	-50.939	2.3032	2.2731	3.6109	2.9477
84400	84060	222.271	-50.879	2.2819	2.2521	3.5766	2.9196
84600	84258	222.332	-50.818	2.2608	2.2313	3.5425	2.8918
84800	84457	222.392	-50.758	2.2399	2.2106	3.5088	2.8643
85000	84655	222.453	-50.697	2.2192 + 1	2.1902 - 2	3.4754 - 2	2.8371 - 2
85200	84853	222.513	-50.637	2.1987	2.1699	3.4424	2.8101
85400	85052	222.574	-50.576	2.1784	2.1499	3.4096	2.7834
85600	85250	222.634	-50.516	2.1583	2.1300	3.3772	2.7569
85800	85448	222.695	-50.455	2.1383	2.1104	3.3451	2.7307
86000	85647	222.755	-50.395	2.1186	2.0909	3.3134	2.7048
86200	85845	222.815	-50.335	2.0990	2.0716	3.2819	2.6791
86400	86044	222.876	-50.274	2.0797	2.0525	3.2507	2.6536
86600	86242	222.936	-50.214	2.0605	2.0335	3.2199	2.6285
86800	86440	222.997	-50.153	2.0415	2.0148	3.1893	2.6035
87000	86639	223.057	-50.093	2.0227 + 1	1.9962 - 2	3.1591 - 2	2.5788 - 2
87200	86837	223.118	-50.032	2.0040	1.9778	3.1291	2.5544
87400	87035	223.178	-49.972	1.9856	1.9596	3.0994	2.5301
87600	87234	223.239	-49.911	1.9673	1.9416	3.0701	2.5062
87800	87432	223.299	-49.851	1.9492	1.9237	3.0410	2.4824
88000	87630	223.360	-49.790	1.9312	1.9060	3.0122	2.4589
88200	87829	223.420	-49.730	1.9135	1.8884	2.9836	2.4356
88400	88027	223.480	-49.670	1.8959	1.8711	2.9554	2.4126
88600	88225	223.541	-49.609	1.8784	1.8539	2.9274	2.3897
88800	88423	223.601	-49.549	1.8611	1.8368	2.8997	2.3671
89000	88622	223.662	-49.488	1.8440 + 1	1.8199 - 2	2.8723 - 2	2.3447 - 2
89200	88820	223.722	-49.428	1.8271	1.8032	2.8451	2.3226
89400	89018	223.783	-49.367	1.8103	1.7866	2.8182	2.3006
89600	89217	223.843	-49.307	1.7937	1.7702	2.7916	2.2789
89800	89415	223.904	-49.246	1.7772	1.7540	2.7652	2.2573
90000	89613	223.964	-49.186	1.7609	1.7379	2.7391	2.2360
90200	89812	224.024	-49.126	1.7448	1.7219	2.7132	2.2149
90400	90010	224.085	-49.065	1.7287	1.7061	2.6876	2.1940
90600	90208	224.145	-49.005	1.7129	1.6905	2.6623	2.1733
90800	90406	224.206	-48.944	1.6972	1.6750	2.6372	2.1528

Altitude		Temperature		Pressure		Density	
Z (ft)	H (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
91000	90605	224.266	-48.884	1.6816 + 1	1.6596 - 2	2.6123 - 2	2.1325 - 2
91200	90803	224.327	-48.823	1.6662	1.6444	2.5876	2.1124
91400	91001	224.387	-48.763	1.6510	1.6294	2.5633	2.0924
91600	91199	224.447	-48.703	1.6358	1.6145	2.5391	2.0727
91800	91398	224.508	-48.642	1.6209	1.5997	2.5152	2.0532
92000	91596	224.568	-48.582	1.6060	1.5850	2.4915	2.0339
92200	91794	224.629	-48.521	1.5913	1.5705	2.4680	2.0147
92400	91992	224.689	-48.461	1.5768	1.5562	2.4448	1.9958
92600	92191	224.750	-48.400	1.5624	1.5419	2.4218	1.9770
92800	92389	224.810	-48.340	1.5481	1.5278	2.3990	1.9584
93000	92587	224.870	-48.280	1.5339 + 1	1.5139 - 2	2.3764 - 2	1.9400 - 2
93200	92785	224.931	-48.219	1.5199	1.5000	2.3541	1.9217
93400	92984	224.991	-48.159	1.5069	1.4863	2.3320	1.9037
93600	93182	225.052	-48.098	1.4923	1.4728	2.3101	1.8858
93800	93380	225.112	-48.038	1.4787	1.4593	2.2884	1.8680
94000	93578	225.173	-47.977	1.4652	1.4460	2.2669	1.8505
94200	93776	225.233	-47.917	1.4518	1.4328	2.2456	1.8331
94400	93975	225.293	-47.857	1.4386	1.4198	2.2245	1.8159
94600	94173	225.354	-47.795	1.4254	1.4060	2.2036	1.7989
94800	94371	225.414	-47.736	1.4125	1.3940	2.1830	1.7820
95000	94569	225.475	-47.675	1.3996 + 1	1.3813 - 2	2.1625 - 2	1.7653 - 2
95200	94767	225.535	-47.615	1.3868	1.3687	2.1422	1.7488
95400	94966	225.595	-47.555	1.3742	1.3562	2.1221	1.7324
95600	95164	225.656	-47.494	1.3617	1.3439	2.1023	1.7161
95800	95362	225.716	-47.434	1.3493	1.3317	2.0826	1.7001
96000	95560	225.777	-47.373	1.3370	1.3195	2.0631	1.6841
96200	95758	225.837	-47.313	1.3249	1.3075	2.0438	1.6684
96400	95956	225.897	-47.253	1.3128	1.2956	2.0246	1.6528
96600	96155	225.958	-47.192	1.3009	1.2839	2.0057	1.6373
96800	96353	226.018	-47.132	1.2890	1.2722	1.9869	1.6220
97000	96551	226.079	-47.071	1.2773 + 1	1.2606 - 2	1.9683 - 2	1.6068 - 2
97200	96749	226.139	-47.011	1.2657	1.2492	1.9499	1.5918
97400	96947	226.199	-46.951	1.2542	1.2378	1.9317	1.5769
97600	97145	226.260	-46.890	1.2428	1.2266	1.9137	1.5622
97800	97343	226.320	-46.830	1.2316	1.2155	1.8958	1.5476
98000	97542	226.381	-46.769	1.2204	1.2044	1.8781	1.5331
98200	97740	226.441	-46.709	1.2093	1.1935	1.8606	1.5188
98400	97938	226.501	-46.649	1.1984	1.1827	1.8432	1.5046
98600	98136	226.562	-46.588	1.1875	1.1720	1.8260	1.4906
98800	98334	226.622	-46.528	1.1767	1.1613	1.8090	1.4767
99000	98532	226.682	-46.468	1.1661 + 1	1.1508 - 2	1.7921 - 2	1.4629 - 2
99200	98730	226.743	-46.407	1.1555	1.1404	1.7754	1.4493
99400	98928	226.803	-46.347	1.1450	1.1301	1.7588	1.4358
99600	99127	226.864	-46.286	1.1347	1.1198	1.7425	1.4224
99800	99325	226.924	-46.226	1.1244	1.1097	1.7262	1.4092
100000	99523	226.984	-46.166	1.1142	1.0997	1.7102	1.3960
100200	99721	227.045	-46.105	1.1041	1.0897	1.6942	1.3830
100400	99919	227.105	-46.045	1.0942	1.0799	1.6785	1.3702
100600	100117	227.166	-45.984	1.0843	1.0701	1.6629	1.3574
100800	100315	227.226	-45.924	1.0745	1.0604	1.6474	1.3448
101000	100513	227.286	-45.864	1.0648 + 1	1.0508 - 2	1.6321 - 2	1.3323 - 2
101200	100711	227.347	-45.803	1.0551	1.0413	1.6169	1.3199
101400	100909	227.407	-45.743	1.0456	1.0319	1.6019	1.3077
101600	101107	227.467	-45.683	1.0362	1.0226	1.5870	1.2955
101800	101305	227.528	-45.622	1.0268	1.0134	1.5723	1.2835
102000	101504	227.588	-45.562	1.0176	1.0043	1.5577	1.2716
102200	101702	227.649	-45.501	1.0084	9.9524 - 3	1.5432	1.2597
102400	101900	227.709	-45.441	9.9934 + 0	9.8627	1.5289	1.2481
102600	102098	227.769	-45.381	9.9033	9.7738	1.5147	1.2365
102800	102296	227.830	-45.320	9.8149	9.6857	1.5006	1.2250
103000	102494	227.890	-45.260	9.7256 + 0	9.5984 - 3	1.4867 - 2	1.2137 - 2
103200	102692	227.950	-45.200	9.6380	9.5120	1.4729	1.2024
103400	102890	228.011	-45.139	9.5512	9.4263	1.4593	1.1913
103600	103088	228.071	-45.079	9.4652	9.3415	1.4458	1.1802
103800	103286	228.131	-45.019	9.3801	9.2574	1.4324	1.1693
104000	103484	228.192	-44.958	9.2957	9.1741	1.4191	1.1585
104200	103682	228.252	-44.898	9.2121	9.0916	1.4060	1.1477
104400	103880	228.312	-44.838	9.1292	9.0099	1.3930	1.1371
104600	104078	228.373	-44.777	9.0472	8.9289	1.3801	1.1266
104800	104276	228.433	-44.717	8.9659	8.8486	1.3673	1.1162
105000	104474	228.494	-44.656	8.8853 + 0	8.7691 - 3	1.3547 - 2	1.1059 - 2
105500	104969	228.644	-44.506	8.6872	8.5736	1.3236	1.0805
106000	105464	229.057	-44.093	8.4937	8.3827	1.2918	1.0545
106500	105959	229.479	-43.671	8.3049	8.1963	1.2608	1.0292
107000	106454	229.902	-43.248	8.1207	8.0145	1.2305	1.0045
107500	106949	230.324	-42.826	7.9408	7.8370	1.2011	9.8046 - 3
108000	107444	230.747	-42.403	7.7653	7.6637	1.1724	9.5703
108500	107938	231.169	-41.981	7.5940	7.4946	1.1444	9.3421
109000	108433	231.591	-41.559	7.4267	7.3296	1.1172	9.1197
109500	108928	232.013	-41.137	7.2635	7.1685	1.0906	8.9030

Table 2-2: Geopotential Altitude, English Altitudes

Altitude		Temperature		Pressure		Density	
H (ft)	Z (ft)	T (K)	t (°C)	P (mb)	P/P_0	ρ (kg/m^3)	ρ/ρ_0
110000	110583	232.929	-40.221	6.9230 + 0	6.8325 - 3	1.0354 - 2	8.4523 - 3
110500	111089	233.355	-39.795	6.7701	6.6816	1.0107	8.2505
111000	111594	233.782	-39.368	6.6209	6.5343	9.8661 - 3	8.0539
111500	112099	234.209	-38.941	6.4752	6.3905	9.6314	7.8624
112000	112605	234.635	-38.515	6.3329	6.2501	9.4027	7.6757
112500	113110	235.062	-38.088	6.1941	6.1131	9.1799	7.4938
113000	113616	235.489	-37.661	6.0585	5.9793	8.9627	7.3165
113500	114121	235.916	-37.234	5.9262	5.8487	8.7510	7.1437
114000	114627	236.342	-36.808	5.7969	5.7211	8.5447	6.9753
114500	115132	236.769	-36.381	5.6707	5.5966	8.3436	6.8111
115000	115638	237.196	-35.954	5.5475 + 0	5.4749 - 3	8.1476 - 3	6.6511 - 3
115500	116143	237.623	-35.527	5.4272	5.3562	7.9566	6.4952
116000	116649	238.049	-35.101	5.3096	5.2402	7.7704	6.3431
116500	117154	238.476	-34.674	5.1949	5.1269	7.5888	6.1949
117000	117660	238.903	-34.247	5.0828	5.0163	7.4118	6.0504
117500	118166	239.329	-33.821	4.9733	4.9083	7.2392	5.9096
118000	118671	239.756	-33.394	4.8664	4.8027	7.0710	5.7722
118500	119177	240.183	-32.967	4.7619	4.6997	6.9069	5.6383
119000	119683	240.610	-32.540	4.6599	4.5990	6.7469	5.5077
119500	120189	241.036	-32.114	4.5602	4.5006	6.5910	5.3804
120000	120695	241.463	-31.687	4.4629 + 0	4.4045 - 3	6.4388 - 3	5.2562 - 3
120500	121200	241.890	-31.260	4.3678	4.3106	6.2905	5.1351
121000	121706	242.316	-30.834	4.2748	4.2189	6.1458	5.0170
121500	122212	242.743	-30.407	4.1840	4.1293	6.0047	4.9018
122000	122718	243.170	-29.980	4.0953	4.0418	5.8671	4.7895
122500	123224	243.597	-29.553	4.0087	3.9562	5.7329	4.6799
123000	123730	244.023	-29.127	3.9240	3.8726	5.6019	4.5730
123500	124236	244.450	-28.700	3.8412	3.[illegible]910	5.4742	4.4687
124000	124742	244.877	-28.273	3.7603	3.7111	5.3496	4.3670
124500	125248	245.303	-27.847	3.6813	3.6331	5.2280	4.2678
125000	125754	245.730	-27.420	3.6040 + 0	3.5569 - 3	5.1094 - 3	4.17[illegible] - 3
125500	126260	246.157	-26.993	3.5285	3.4824	4.9937	4.0765
126000	126766	246.584	-26.566	3.4547	3.4096	4.8809	3.984[illegible]
126500	127272	247.010	-26.140	3.3826	3.3384	4.7707	3.8945
127000	127778	247.437	-25.713	3.3121	3.2688	4.6632	3.8067
127500	128284	247.864	-25.286	3.2432	3.2008	4.5584	3.7211
128000	128790	248.291	-24.859	3.1759	3.1343	4.4560	3.6376
128500	129297	248.717	-24.433	3.1100	3.0694	4.3562	3.5560
129000	129803	249.144	-24.006	3.0456	3.0058	4.2587	3.4765
129500	130309	249.571	-23.579	2.9827	2.9437	4.1636	3.3988
130000	130815	249.997	-23.153	2.9212 + 0	2.8830 - 3	4.0707 - 3	3.32[illegible]0 - 3
130500	131322	250.424	-22.726	2.8610	2.8236	3.9801	3.2490
131000	131828	250.851	-22.299	2.8022	2.7656	3.8916	3.1768
131500	132334	251.278	-21.872	2.7447	2.7088	3.8053	3.1064
132000	132841	251.704	-21.446	2.6885	2.6533	3.7210	3.0375
132500	133347	252.131	-21.019	2.6335	2.5991	3.6387	2.9704
133000	133854	252.558	-20.592	2.5797	2.5459	3.5584	2.9046
133500	134360	252.984	-20.166	2.5271	2.4940	3.4800	2.8408
134000	134867	253.411	-19.739	2.4757	2.4433	3.4034	2.7783
134500	135373	253.839	-19.312	2.4254	2.3936	3.3286	2.7172
135000	135880	254.265	-18.885	2.3762 + 0	2.3451 - 3	3.2556 - 3	2.6577 - 3
135500	136386	254.691	-18.459	2.3280	2.2976	3.1844	2.5995
136000	136893	255.118	-18.032	2.2810	2.2511	3.1148	2.5427
136500	137399	255.545	-17.605	2.2349	2.2057	3.0468	2.4872
137000	137906	255.971	-17.179	2.1899	2.1612	2.9804	2.4330
137500	138413	256.398	-16.752	2.1458	2.1178	2.9156	2.3801
138000	138919	256.825	-16.325	2.1027	2.0752	2.8523	2.3284
138500	139426	257.252	-15.898	2.0606	2.0336	2.7905	2.2779
139000	139933	257.678	-15.47[illegible]	2.0193	1.9929	2.7301	2.2286
139500	140439	258.105	-15.045	1.9790	1.9531	2.6711	2.1805
140000	140946	258.532	-14.618	1.9395 + 0	1.9141 - 3	2.6135 - 3	2.1334 - 3
140500	141453	258.959	-14.191	1.9008	1.8760	2.5572	2.0875
141000	141960	259.385	-13.765	1.8630	1.8387	2.502[illegible]	2.0426
141500	142467	259.812	-13.338	1.8260	1.8021	2.4485	1.9988
142000	142974	260.239	-12.911	1.7898	1.7664	2.3960	1.9559
142500	143480	260.665	-12.485	1.7544	1.7315	2.3448	1.9141
143000	143987	261.092	-12.058	1.7197	1.6972	2.2947	1.8732
143500	144494	261.519	-11.631	1.6858	1.6638	2.2457	1.8332
144000	145001	261.946	-11.204	1.6526	1.6310	2.1979	1.7942
144500	145508	262.372	-10.778	1.6201	1.5989	2.1512	1.7561
145000	146015	262.799	-10.351	1.5883 + 0	1.5675 - 3	2.1055 - 3	1.7188 - 3
145500	146522	263.226	-9.924	1.5572	1.5368	2.0609	1.6824
146000	147029	263.652	-9.498	1.5267	1.5067	2.0173	1.6468
146500	147536	264.079	-9.071	1.4969	1.4773	1.9747	1.6120
147000	148044	264.506	-8.644	1.4677	1.4485	1.9331	1.5780
147500	148551	264.933	-8.217	1.4391	1.4203	1.8924	1.5448
148000	149058	265.359	-7.791	1.4111	1.3926	1.8526	1.5123
148500	149565	265.786	-7.364	1.3837	1.3656	1.8137	1.4806
149000	150072	266.213	-6.937	1.3569	1.3391	1.7757	1.4495
149500	150579	266.639	-6.511	1.3306	1.3132	1.7385	1.4192

REFERENCES

1. Little, Arthur D., Inc., "Hybrid Oxygen Systems Analysis", Phase I Report, Contract Number F33615-86-C-4504, May 1987.

2. Eng, E. G., A. Gupta, A. J. P. Lloyd, J. K. Robinson, "Tactical Life Support System", Final Report for August 1983 - April 1987, D449-10021, Boeing Military Airplane Company, May 1987.

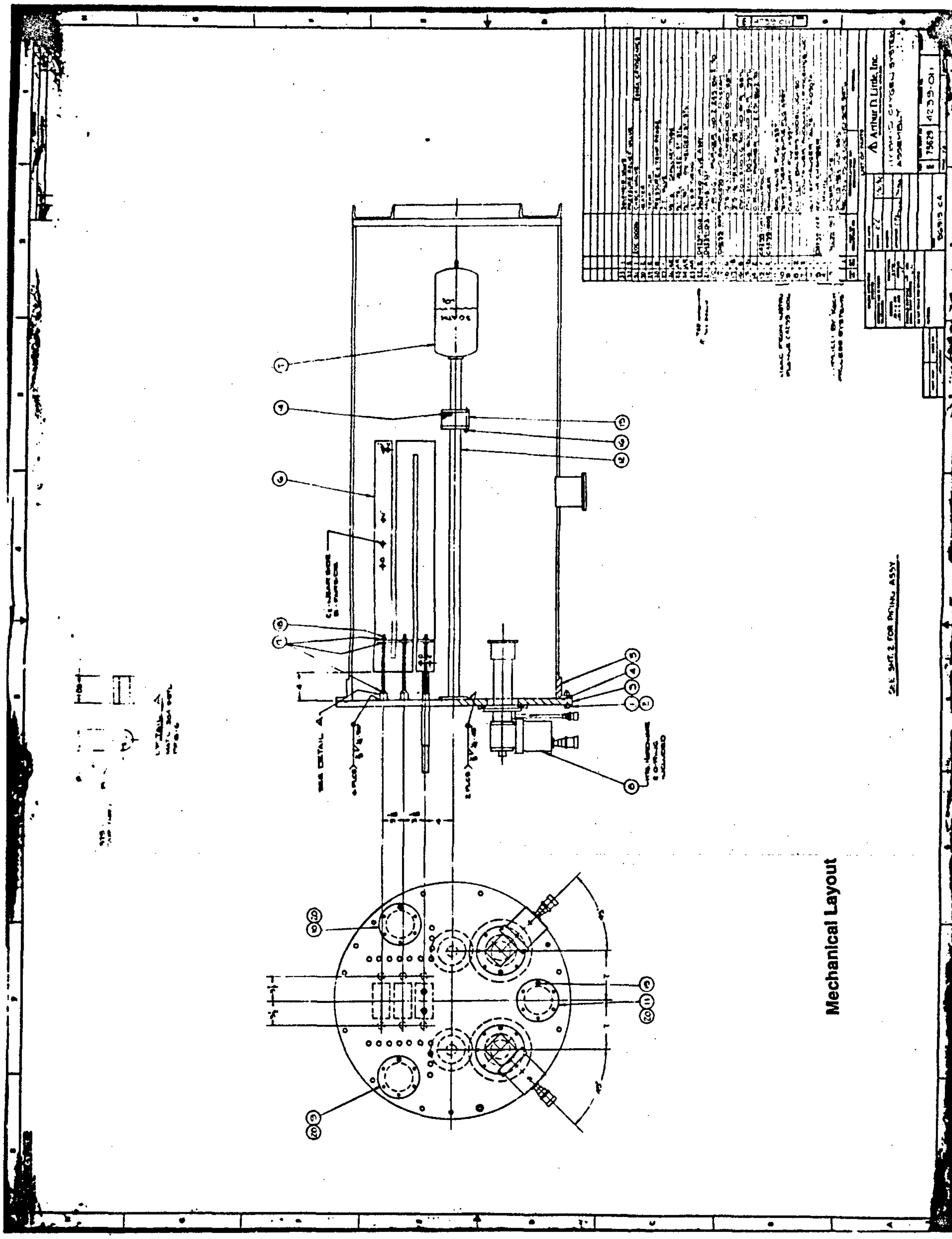
3. Garrett AiResearch, "Performance data, Environmental Control System Performance Characteristics for McAir F-15 Aircraft", Volume I of II, 12 April 1973.

4. Letton, George C., "Survey of Fighter Aircraft Environmental Control Systems", Aeronautical Systems Division, Wright-Patterson AFB, presented at SAE AC-9 Committee Meeting, San Francisco, CA., 6 May 1976.

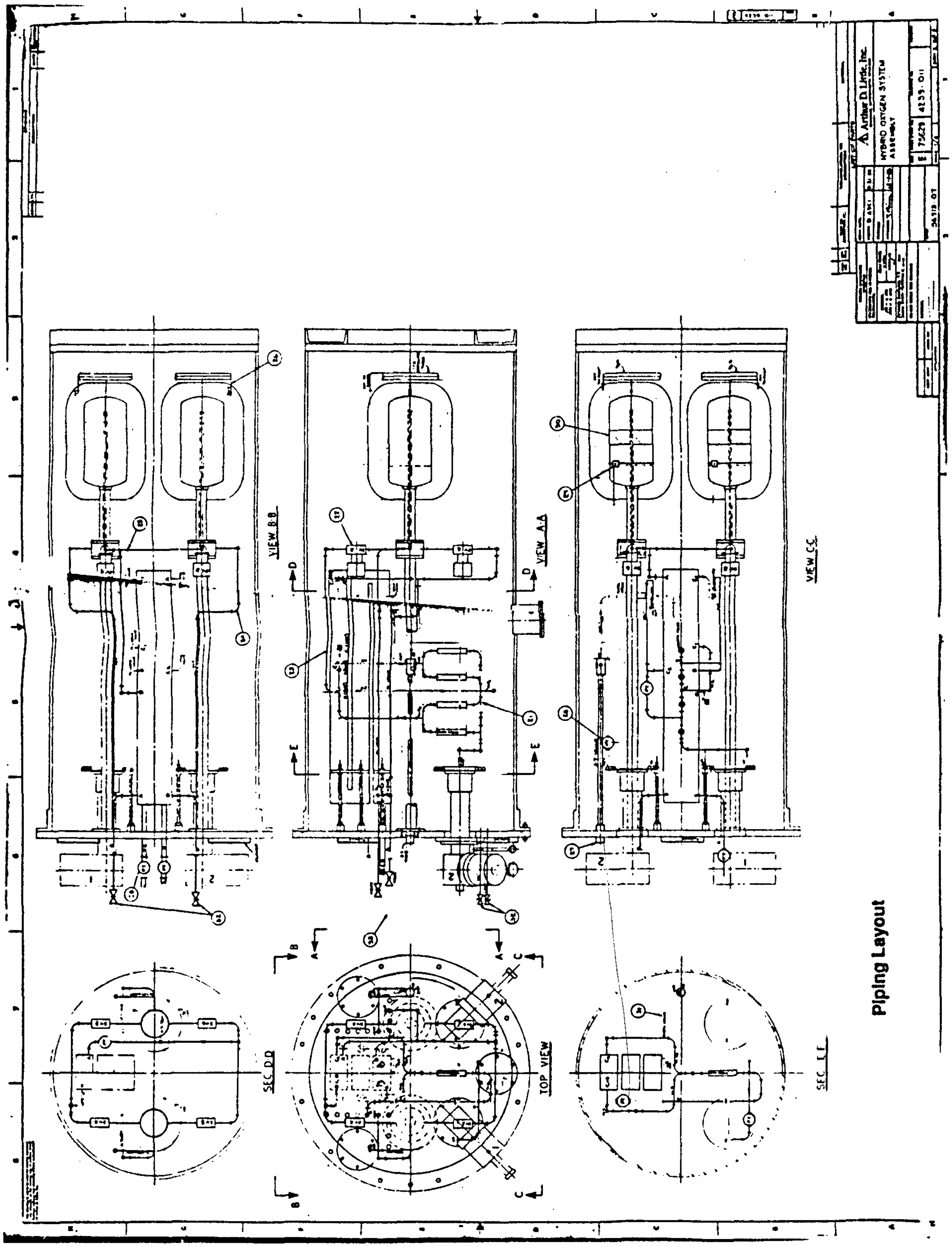
5. U. S. Standard Atmosphere, 1976, National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, United States Air Force, NOAA-S/T 76-1562, Washington, D. C., October 1976.

7.3 Engineering Drawings

7.3.1 Mechanical and Piping Layout

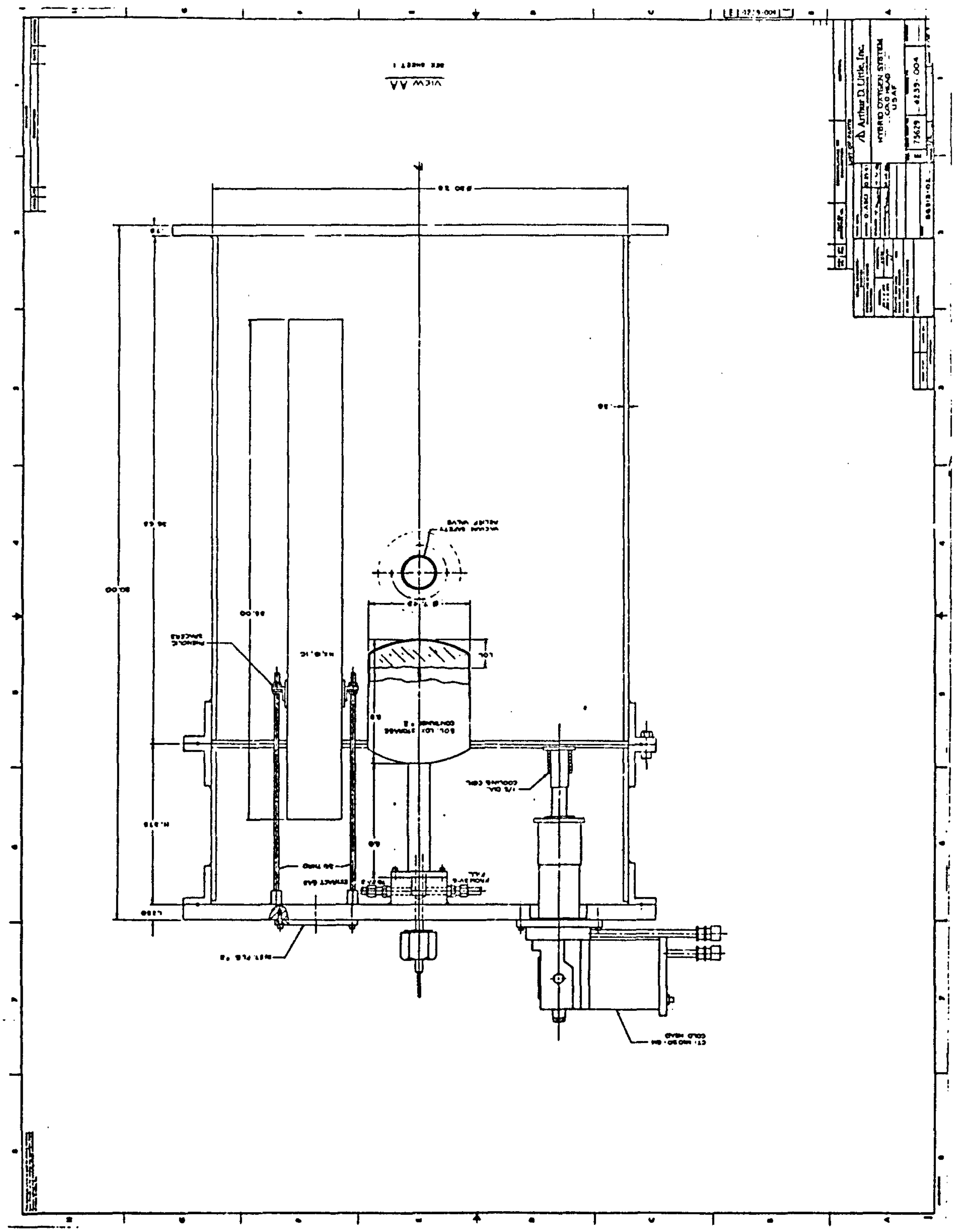


Mechanical Layout

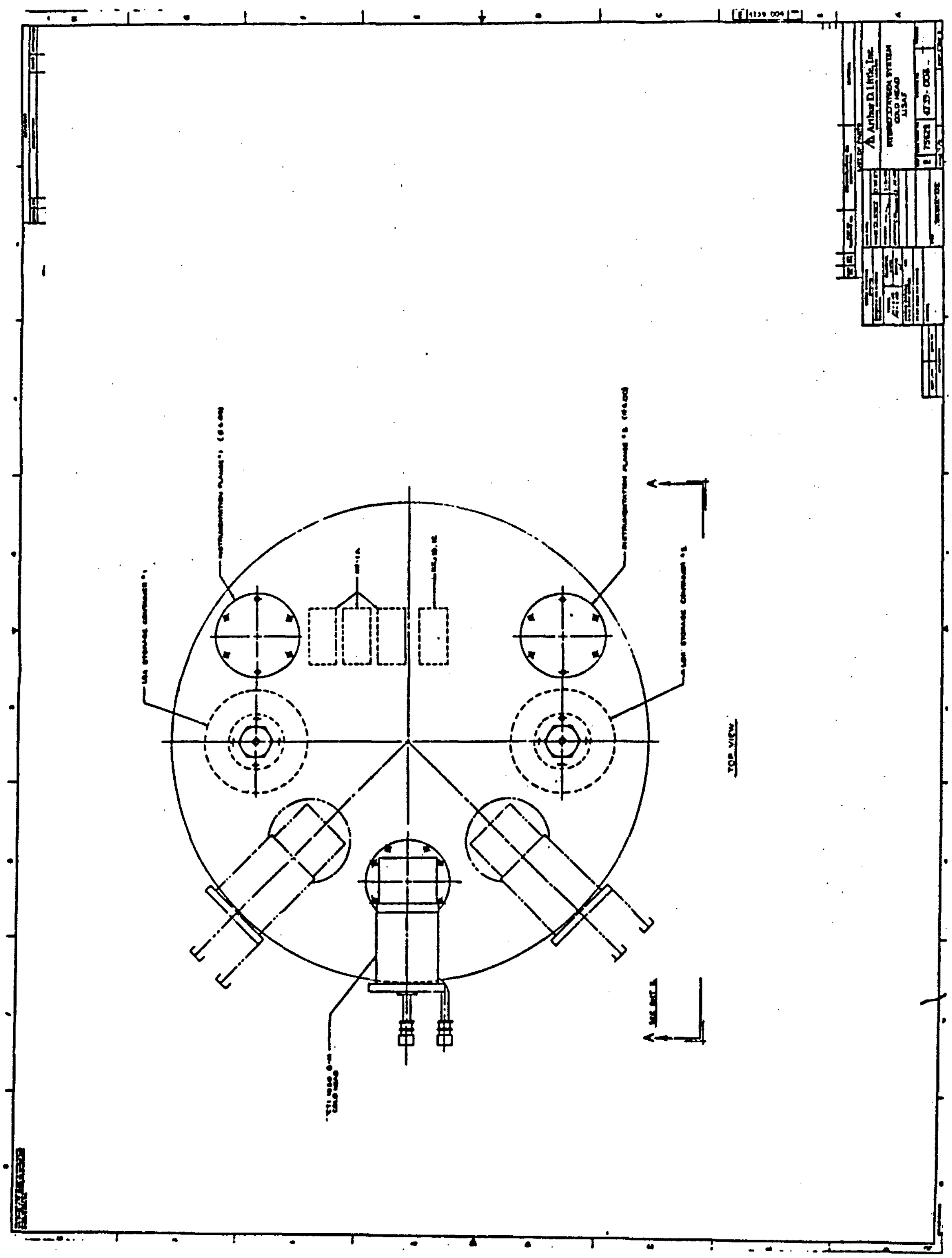


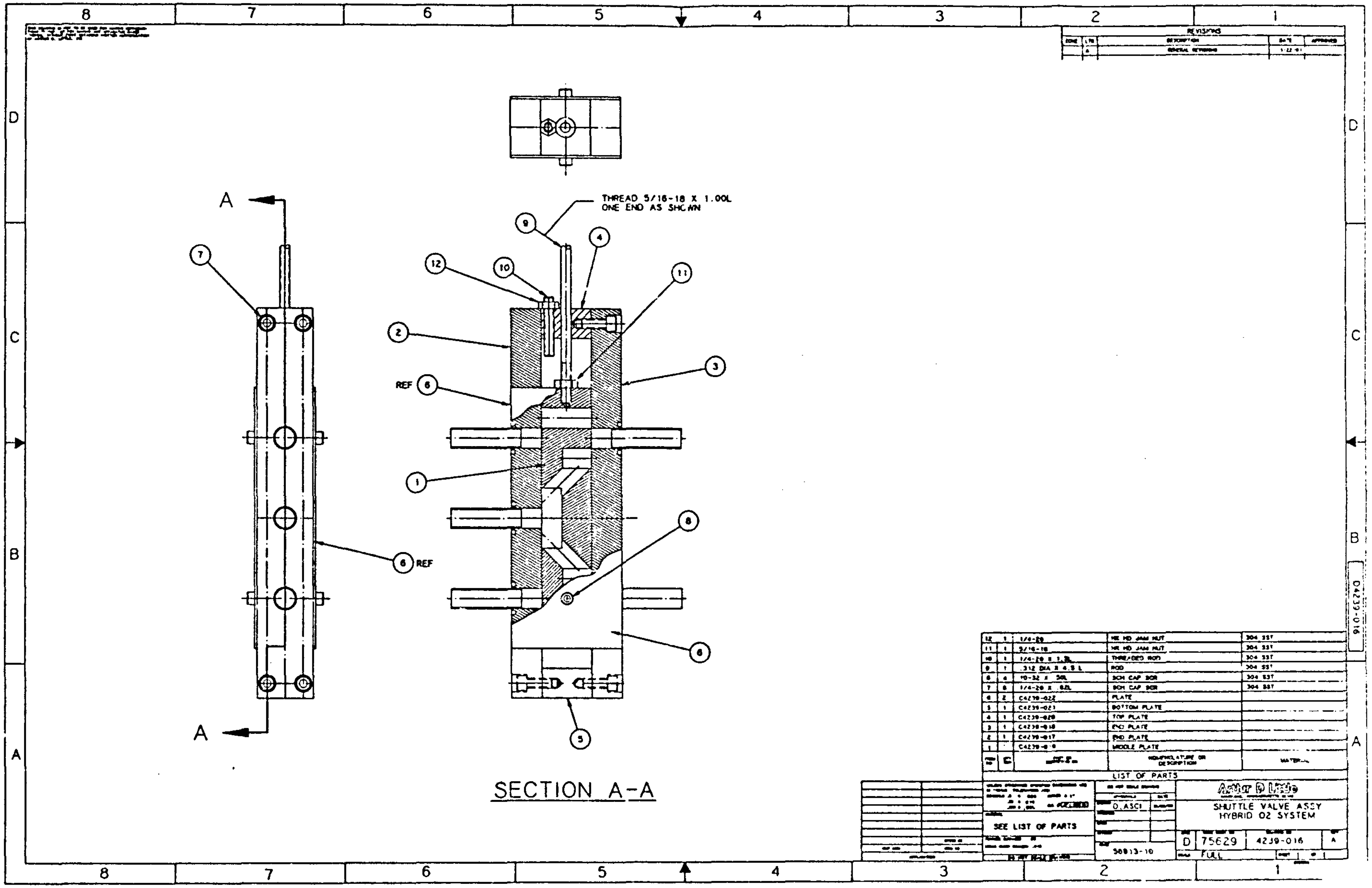
Piping Layout

7.3.2 Mechanical Drawings

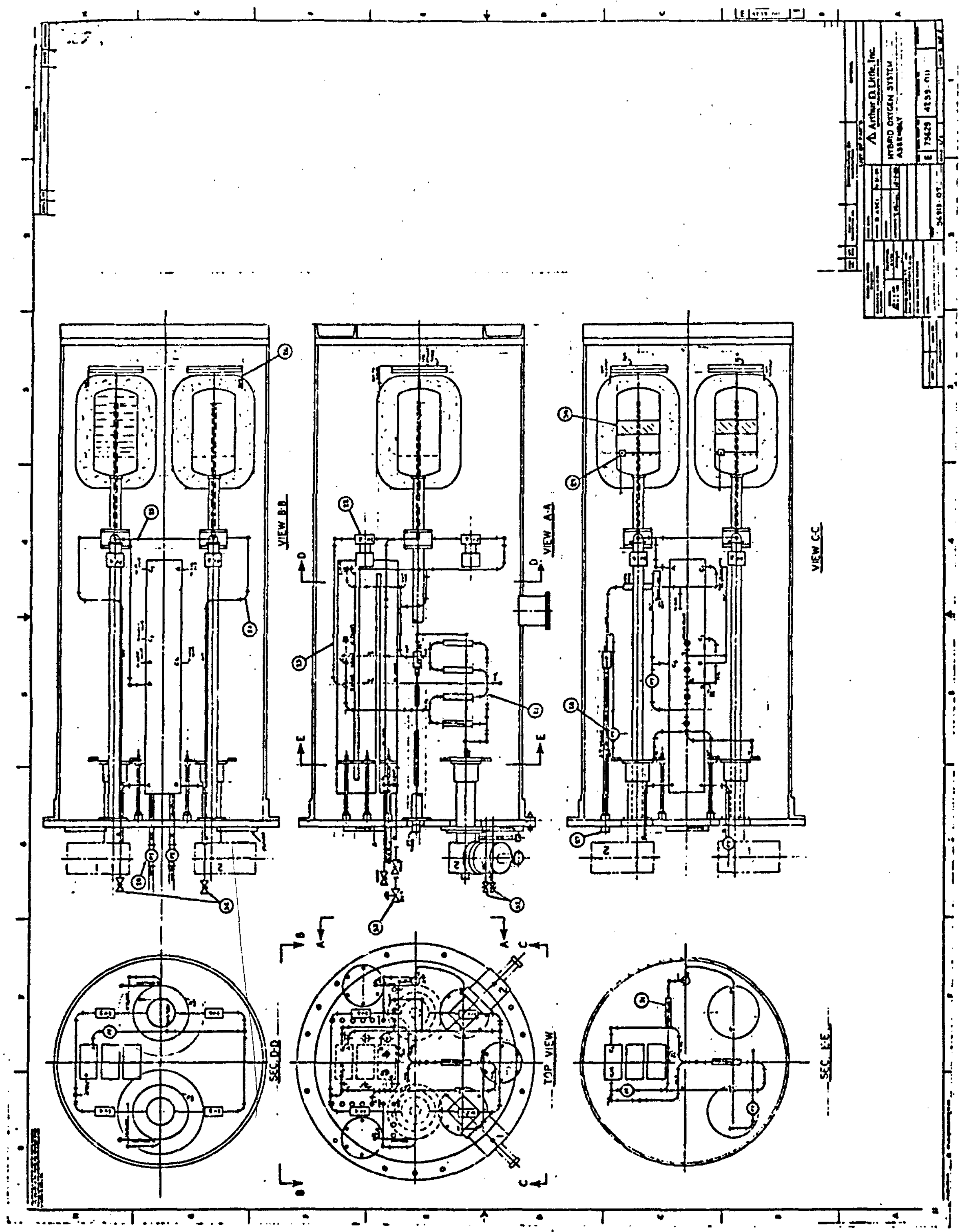


VIEW AA
Arthur D. Little, Inc.
HYBRID OXYGEN SYSTEM

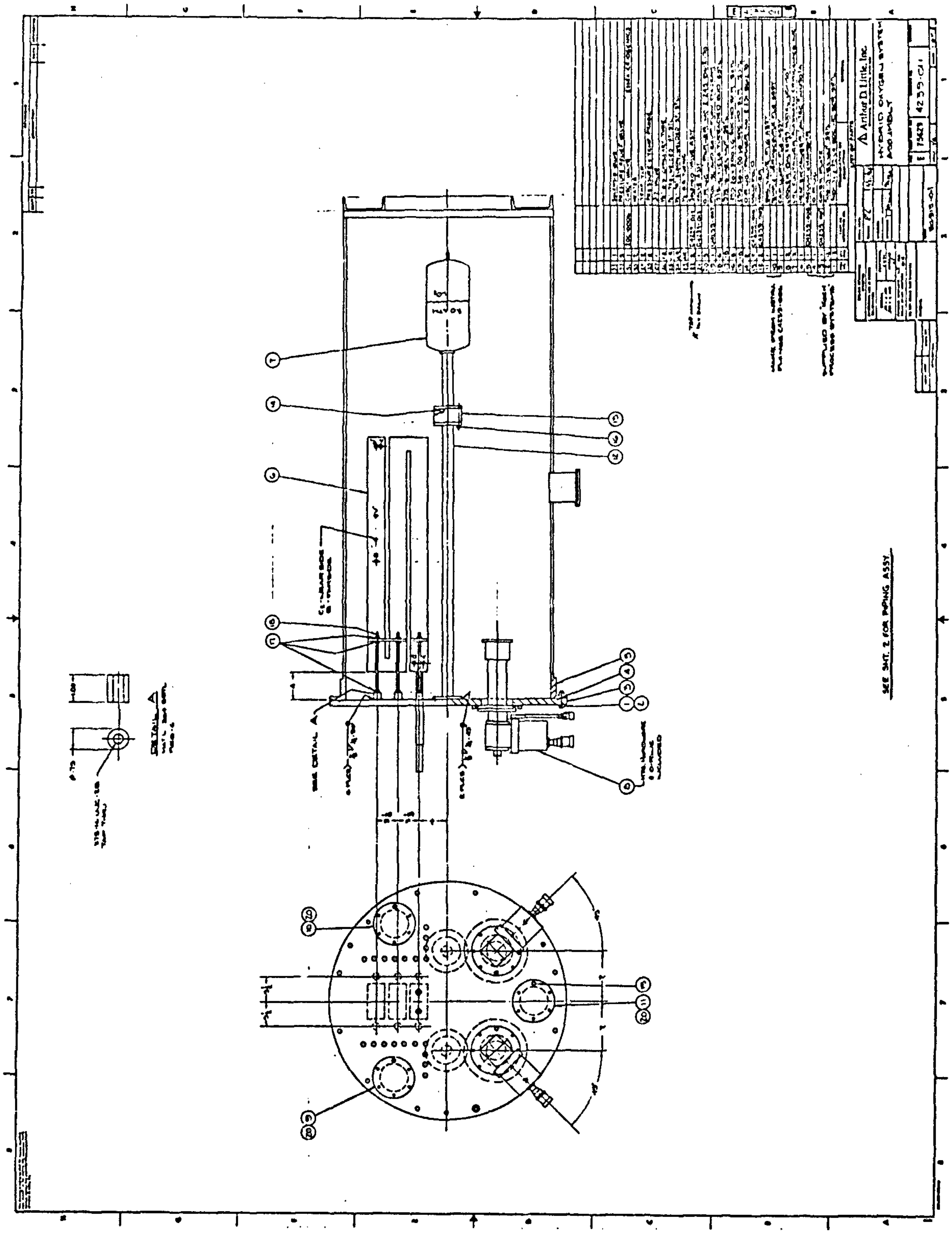

TOP VIEW
Arthur D. Little, Inc.
COLD HEAD
USAF



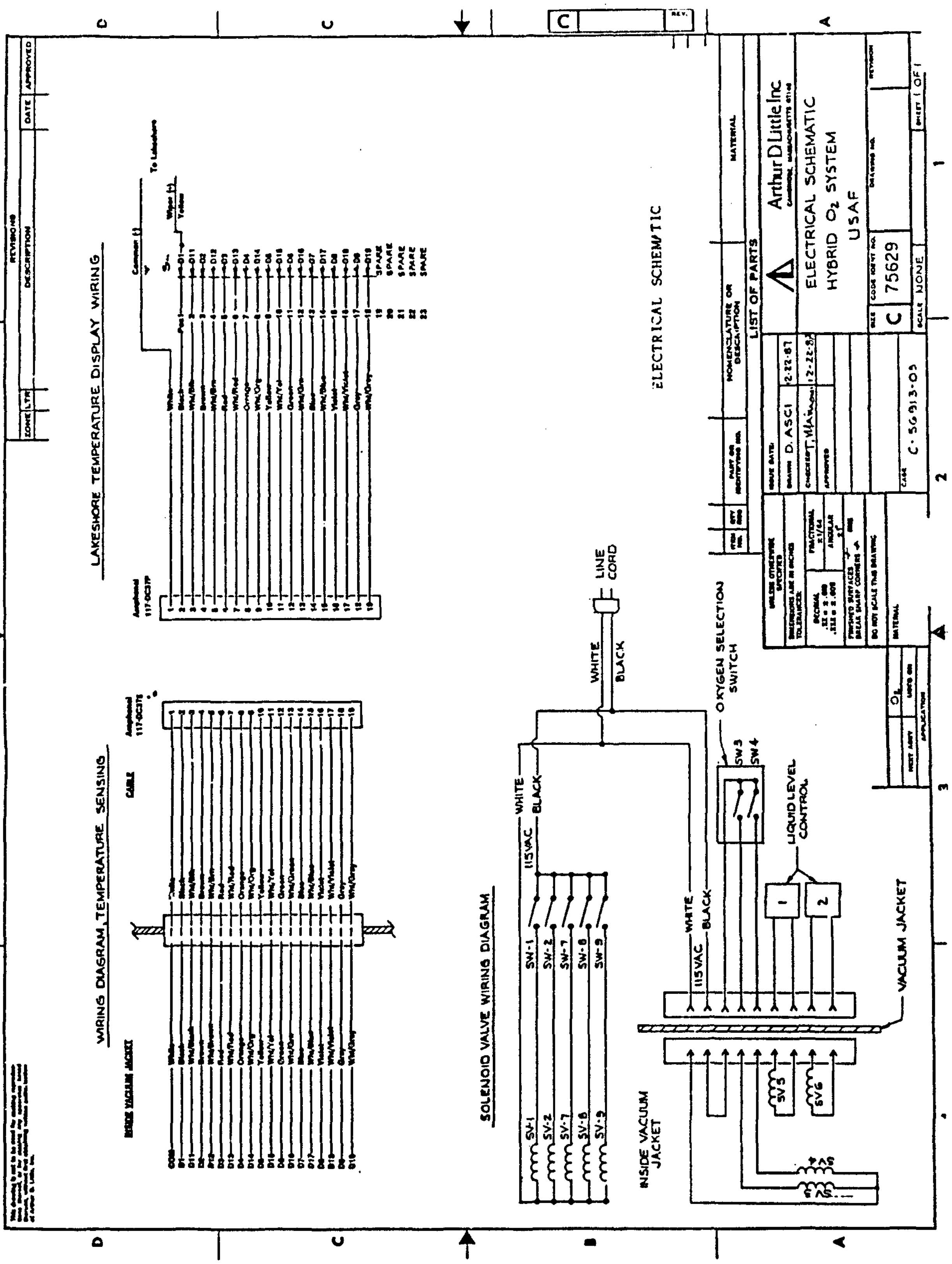
D4239-016
REVISIONS
GENERAL REVISIONS
THREAD 5/16-18 X 1.00L
ONE END AS SHOWN
REF
SECTION A-A
A
12 1 1/4-20 HX HD JAM NUT 304 SST
11 1 5/16-18 HX HD JAM NUT 304 SST
10 1 1/4-20 X 1.3L THREADED ROD 304 SST
9 1 .312 DIA X 4.5 L ROD 304 SST
8 4 10-32 X .50L SCH CAP SCR 304 SST
7 8 1/4-20 X .62L SCH CAP SCR 304 SST
6 2 C4239-022 PLATE
5 1 C4239-021 BOTTOM PLATE
4 1 C4239-020 TOP PLATE
3 1 C4239-018 END PLATE
2 1 C4239-017 END PLATE
1 C4239-019 MIDDLE PLATE
NOMENCLATURE OR DESCRIPTION
LIST OF PARTS
SEE LIST OF PARTS
D.ASCI
Arthur D Little
SHUTTLE VALVE ASSY
HYBRID O2 SYSTEM
D 75629 4239-016 A
50813-10
FULL
1 1



VIEW B-B
VIEW A-A
VIEW C-C
TOP VIEW
SEC. D-D
SEC. E-E
Arthur D. Little, Inc.
HYBRID OXYGEN SYSTEM ASSEMBLY


SEE SHT. 2 FOR PIPING ASSY
Arthur D. Little, Inc.

7.3.3 Electrical Drawings


ELECTRICAL SCHEMATIC
HYBRID O2 SYSTEM
USAF
Arthur D Little Inc
LIST OF PARTS
75629
NONE
C-56913-05
LAKESHORE TEMPERATURE DISPLAY WIRING
WIRING DIAGRAM, TEMPERATURE SENSING
SOLENOID VALVE WIRING DIAGRAM
OXYGEN SELECTION SWITCH
LIQUID LEVEL CONTROL
VACUUM JACKET
INSIDE VACUUM JACKET
LINE CORD
WHITE
BLACK
115VAC

7.4 Essex Cryogenics Concentrator Performance

60 psig = 5.08 ATM

Essex Cryogenics Molecular Sieve
Unit Performance

60C 8082-2

OBOES

	Alt.		Air In		O_2 Enriched Air Out					
	A/C	Cabin	Pres. (PSIG)	Flow (LPM)	Pres. (PSIG)	Flow (LPM)	% O_2	% A	% N_2	Amps
10	0	0	10	192	3.0	10	70.7	3.27	26.0	0.43
20	0	0	10	204	2.7	25	37.2	1.72	60.7	0.43
30	0	0	10	204	2.3	40	29.8	1.36	68.8	0.43
40	0	0	10	204	2.0	50	27.6	1.25	71.0	0.43
50	0	0	10	204	2.0	52	27.1	1.23	71.6	0.43
60	0	0	20	396	6.9	10	94.5	5.11	0.4	0.50
70	0	0	20	396	6.8	25	84.3	3.92	11.7	0.50
80	0	0	20	396	6.4	40	58.9	2.73	38.3	0.50
90	0	0	20	396	6.1	50	50.3	2.33	47.0	0.50
100	0	0	20	403	5.9	60	44.5	2.06	53.3	0.50
110	0	0	20	408	5.5	75	39.2	1.81	58.7	0.50
120	0	0	20	406	5.0	91	35.3	1.63	63.0	0.50
130	0	0	30	589	10.9	10	93.5	5.94	0.5	0.57
140	0	0	30	589	10.7	25	95.0	4.69	0.3	0.57
150	0	0	30	589	10.6	40	87.5	4.08	8.2	0.57
160	0	0	30	[illegible] scfm 589	10.3	50	75.4	3.50	20.9	0.57
170	0	0	30	589	10.0	60	65.8	3.05	31.2	0.57
180	0	0	30	589	9.6	75	56.2	2.63	40.8	0.57
190	0	0	30	22.4 600	8.9	100	46.3	2.20	51.3	0.57
200	0	0	40	770	15.6	10	93.5	6.10	0.3	0.67
210	0	0	40	775	15.2	25	94.7	4.99	0.3	0.67
220	0	0	40	781	14.9	40	95.0	4.59	0.3	0.67
230	0	0	40	781	14.7	50	91.1	4.34	4.3	0.67
240	0	0	40	781	14.6	60	86.4	4.03	9.4	0.67
250	0	0	40	781	14.1	75	73.4	3.40	23.1	0.67
260	0	0	40	792	13.4	100	59.1	2.75	38.0	0.67
270	0	0	60	883	18.7	10	93.8	5.83	0.3	0.70
280	0	0	60	889	18.4	25	94.7	5.00	0.3	0.70
290	0	0	60	900	18.2	40	95.0	4.62	0.4	0.70
300	0	0	60	883	18.0	50	94.1	.47	1.3	0.70
310	0	0	60	894	17.8	60	90.2	.24	5.5	0.70
320	0	0	60	894	17.4	75	80.0	3.70	16.3	0.70
330	0	0	60	362 $\boxed{883}$	16.8	100	65.0	3.00	32.0	0.70
340	10.0	8.0	10	197	3.2	10	85.1	.02	11.1	0.43
350	10.0	8.0	10	192	2.8	25	51.3	2.35	46.5	0.43
360	10.0	8.0	10	197	2.5	40	38.3	.74	59.8	0.43
370	10.0	8.0	10	199	2.4	50	34.4	.55	63.9	0.43
380	10.0	8.0	10	199	2.2	54	32.7	.47	65.6	0.43
390	10.0	8.0	20	389	7.3	10	94.2	5.40	0.3	0.47
400	10.0	8.0	20	389	7.1	25	93.9	.51	1.5	0.47
410	10.0	8.0	20	389	7.0	40	81.8	3.79	14.4	0.47
420	10.0	8.0	20	389	6.7	50	67.8	.12	28.9	0.47
430	10.0	8.0	20	389	6.4	60	59.6	2.73	37.5	0.47
440	10.0	8.0	20	392	6.2	75	50.5	2.32	46.5	0.47
450	10.0	8.0	20	396	5.5	100	41.5	.92	56.2	0.47
460	10.0	8.0	30	566	11.6	10	93.7	.08	0.2	0.53
470	10.0	8.0	30	573	11.4	25	94.8	.96	0.2	0.53
480	10.0	8.0	30	577	11.2	40	95.1	.57	0.3	0.53
490	10.0	8.0	30	575	11.0	50	93.6	.38	1.9	0.53
500	10.0	8.0	30	573	10.8	60	86.8	.02	9.2	0.53
510	10.0	8.0	30	568	10.6	75	74.0	.42	22.3	0.53
520	10.0	8.0	30	571	10.1	100	59.5	.75	37.2	0.53
530	10.0	8.0	40	724	16.2	10	93.4	.33	0.2	0.60
540	10.0	8.0	40	736	15.9	25	94.6	.17	0.2	0.60
550	10.0	8.0	40	736	15.6	[illegible]	95.0	.76	0.2	0.60
560	10.0	8.0	40	73[illegible]	15.4	[illegible]	[illegible]	.59	[illegible]	0.60
570	10.0	8.0	40	736	15.2	[illegible]	[illegible]	.47	0.5	0.60
580	10.0	8.0	40	736	15.0	[illegible]	[illegible]	.10	5.8	0.60
590	10.0	8.0	[illegible]	731	14.6	[illegible]	[illegible]	.92	22.5	0.60
600	10.0	8.0	60	830	19.6	10	93.6	.19	0.2	0.65
610	10.0	8.0	60	83[illegible]	19.2	[illegible]	94.6	.16	0.2	0.65
620	10.0	8.0	60	84[illegible]	19.[illegible]	[illegible]	95.[illegible]	.78	0.2	0.65

Essex Cryogenics Molecular Sieve
Unit Performance (continued)

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	% O_2	% A	% N_2	[illegible]
630	10.0	8.0	60	838	19.0	50	94.9	4.63	0.4	0.65
640	10.0	8.0	60	849	18.6	60	94.5	4.51	0.9	0.65
650	10.0	8.0	60	842	18.4	75	91.7	4.28	3.9	0.65
660	10.0	8.0	60	826	18.0	100	79.4	3.68	16.9	0.65
670	20.0	8.0	20	363	7.3	10	94.3	5.50	0.2	0.45
680	20.0	8.0	20	365	7.0	25	94.8	4.55	0.6	0.45
690	20.0	8.0	20	365	6.7	40	83.5	3.90	12.2	0.45
700	20.0	8.0	20	367	6.5	50	71.5	3.29	25.3	0.45
710	20.0	8.0	20	369	6.2	60	60.6	2.83	36.5	0.45
720	20.0	8.0	20	369	6.2	63	59.7	2.76	37.5	0.45
730	20.0	8.0	30—	532	12.0	10	93.6	6.17	0.2	0.51
740	20.0	8.0	30	543	11.7	25	94.7	5.03	0.2	0.51
750	20.0	8.0	30	548	11.4	40	95.1	4.61	0.2	0.51
760	20.0	8.0	30 3	548	11.1	50	95.0	4.46	0.5	0.51
770	20.0	8.0	30	548	10.9	60	92.3	4.27	3.8	0.51
780	20.0	8.0	30	550	10.6	75	78.9	3.65	17.3	0.51
790	20.0	8.0	30—	552	10.1	100	63.4	2.94	33.4	0.51
800	20.0	8.0	40	668	17.1	10	93.7	6.03	0.2	0.61
810	20.0	8.0	40	670	16.9	25	94.7	5.08	0.2	0.61
820	20.0	8.0	40	668	16.6	40	95.0	4.68	0.3	0.61
830	20.0	8.0	40	677	16.5	50	94.9	4.52	0.5	0.61
840	20.0	8.0	40	679	16.3	60	93.9	4.38	1.7	0.61
850	20.0	8.0	40	684	15.8	75	88.3	4.10	7.6	0.61
860	20.0	8.0	40	691	15.2	100	74.6	3.42	21.7	0.61
870	20.0	8.0	60	781	20.4	10	93.7	6.02	0.2	0.64
880	20.0	8.0	60	792	20.0	25	94.6	5.16	0.2	0.64
890	20.0	8.0	60	804	19.7	40	94.9	4.78	0.2	0.64
900	20.0	8.0	60	804	19.6	50	95.0	4.64	0.3	0.64
910	20.0	8.0	60	804	19.5	60	94.6	4.52	0.8	0.64
920	20.0	8.0	60	797	19.0	75	91.9	4.20	3.9	0.64
930	20.0	8.0	60	797	18.6	100	79.9	3.68	16.0	0.64
940	20.0	20.0	10	181	3.3	10	94.9	4.80	0.3	0.41
950	20.0	20.0	10	181	3.2	25	79.6	3.75	16.4	0.41
960	20.0	20.0	10	181	2.9	40	55.5	2.55	41.5	0.41
970	20.0	20.0	10	181	2.8	50	48.9	2.20	49.0	0.41
980	20.0	20.0	10	183	2.6	60	42.5	2.00	55.0	0.41
990	20.0	20.0	10	183	2.4	75	38.0	1.76	59.8	0.41
1000	20.0	20.0	10	183	2.1	86	35.3	1.70	62.9	0.41
1010	20.0	20.0	20	357	7.7	10	93.2	6.04	0.7	0.46
1020	20.0	20.0	20	357	7.5	25	94.6	4.92	0.5	0.46
1030	20.0	20.0	20	357	7.3	40	93.9	4.51	1.4	0.46
1040	20.0	20.0	20	357	7.2	50	92.4	4.30	2.9	0.46
1050	20.0	20.0	20	357	7.1	60	88.3	4.10	7.2	0.46
1060	20.0	20.0	20	360	6.9	75	75.1	3.50	19.9	0.46
1070	20.0	20.0	20	362	6.4	100	60.5	2.83	36.5	0.46
1080	20.0	20.0	30—	537	12.4	10	93.0	6.82	0.2	0.52
1090	20.0	20.0	30	532	12.3	25	94.3	5.49	0.2	0.52
1100	20.0	20.0	30	534	12.1	40	94.8	4.98	0.2	0.52
1110	20.0	20.0	30	537	12.0	50	95.0	4.77	0.2	0.52
1120	20.0	20.0	30	534	11.9	60	95.0	4.63	0.2	0.52
1130	20.0	20.0	30	532	11.8	75	94.3	4.45	1.1	0.52
1140	20.0	20.0	30	532	11.5	100	87.3	4.04	8.5	0.52
1150	20.0	20.0	40	688	17.2	10	92.9	6.95	0.2	0.57
1160	20.0	20.0	40	679	17.2	25	94.1	5.70	0.2	0.57
[illegible]	20.0	20.0	40	684	17.0	40	94.6	5.20	0.1	0.57
[illegible]	20.0	20.0	40	688	16.8	50	94.8	4.96	0.2	0.57
[illegible]	20.0	20.0	40	688	16.7	60	95.0	4.81	0.2	0.57
[illegible]	20.0	20.0	40	691	[illegible]	75	95.1	4.64	0.2	0.57
[illegible]	20.0	20.0	[illegible]	691	[illegible]	100	94.9	4.45	0.5	0.57
[illegible]	20.0	20.0	[illegible]	[illegible]	[illegible]	10	93.6	6.15	0.2	0.62
1230	20.0	20.0	[illegible]	770	20.4	25	94.2	5.60	0.2	0.62
1240	20.0	20.0	60	771	20.3	40	94.7	5.16	0.1	0.62
1250	20.0	20.0	60	779	20.2	50	94.8	5.00	0.1	0.62

Essex Cryogenics Molecular Sieve
Unit Performance (continued)

1260	20.0	20.0	60	788	20.1	60	94.9	4.82	0.2	0.62
1270	20.0	20.0	60	792	20.0	75	94.7	4.66	0.4	0.62
1280	20.0	20.0	60	788	19.7	100	94.5	4.87	0.9	0.62
1290	30.0	11.9	20	328	7.9	10	93.5	5.40	0.2	0.43
1300	30.0	11.9	20	335	7.6	25	94.2	5.05	0.6	0.43
1310	30.0	11.9	20	335	7.3	40	90.9	4.45	4.5	0.43
1320	30.0	11.9	20	335	7.1	50	79.1	3.69	16.5	0.43
1330	30.0	11.9	20	335	6.8	61	67.0	3.05	29.8	0.43
1340	30.0	11.9	30	498	12.7	10	93.1	6.73	0.2	0.48
1350	30.0	11.9	30	503	12.3	25	94.2	5.54	0.2	0.48
1360	30.0	11.9	30	507	12.1	40	94.8	5.11	0.2	0.48
1370	30.0	11.9	30	509	12.0	50	94.6	4.97	0.4	0.48
1380	30.0	11.9	30	509	11.9	60	94.0	4.80	1.2	0.48
1390	30.0	11.9	30	507	11.5	75	84.2	3.89	11.8	0.48
1400	30.0	11.9	30	509	10.9	100	67.0	3.10	30.0	0.48
1410	30.0	11.9	40	661	17.7	10	93.0	6.85	0.2	0.56
1420	30.0	11.9	40	656	17.4	25	94.0	5.81	0.1	0.56
1430	30.0	11.9	40	666	17.2	40	94.5	5.31	0.2	0.56
1440	30.0	11.9	40	668	17.0	50	94.7	5.12	0.2	0.56
1450	30.0	11.9	40	668	16.8	60	94.7	5.00	0.3	0.56
1460	30.0	11.9	40	668	16.6	75	94.3	4.81	0.9	0.56
1470	30.0	11.9	40	668	16.1	100	83.3	3.80	12.9	0.56
1480	30.0	11.9	60	758	21.2	10	93.4	6.36	0.2	0.62
1490	30.0	11.9	60	756	20.8	25	94.0	5.76	0.1	0.62
1500	30.0	11.9	60	763	20.4	40	94.5	5.35	0.1	0.62
1510	30.0	11.9	60	765	20.2	50	94.6	5.20	0.2	0.62
1520	30.0	11.9	60	765	20.1	60	94.5	5.05	0.4	0.62
1530	30.0	11.9	60	770	20.0	75	93.1	4.75	2.1	0.62
1540	30.0	11.9	60	761	19.9	100	86.8	4.19	8.7	0.62
1550	30.0	30.0	10	149	3.4	10	94.2	5.25	0.5	0.40
1560	30.0	30.0	10	152	3.3	25	93.8	4.46	1.7	0.40
1570	30.0	30.0	10	152	3.3	40	78.4	3.60	18.0	0.40
1580	30.0	30.0	10	154	3.1	50	67.0	3.07	30.0	0.40
1590	30.0	30.0	10	154	2.9	60	58.5	2.75	38.7	0.40
1600	30.0	30.0	10	152	2.7	75	50.5	2.38	47.0	0.40
1610	30.0	30.0	10	161	2.4	100	42.5	1.98	55.2	0.40
1620	30.0	30.0	20	317	8.0	10	92.8	6.92	0.3	0.44
1630	30.0	30.0	20	319	7.9	25	94.3	5.41	0.2	0.44
1640	30.0	30.0	20	321	7.8	40	94.9	4.90	0.2	0.44
1650	30.0	30.0	20	326	7.7	50	95.0	4.72	0.2	0.44
1660	30.0	30.0	20	328	7.6	60	95.1	4.60	0.2	0.44
1670	30.0	30.0	20	324	7.4	75	94.9	4.46	0.5	0.44
1680	30.0	30.0	20	326	7.2	100	84.0	3.92	11.9	0.44
1690	30.0	30.0	30	475	13.0	10	92.2	7.62	0.2	0.52
1700	30.0	30.0	30	475	13.0	25	93.8	6.02	0.1	0.52
1710	30.0	30.0	30	475	12.9	40	94.4	5.40	0.1	0.52
1720	30.0	30.0	30	475	12.8	50	94.7	5.11	0.1	0.52
1730	30.0	30.0	30	475	12.7	60	94.9	4.93	0.1	0.52
1740	30.0	30.0	30	475	12.6	75	95.1	4.74	0.1	0.52
1750	30.0	30.0	30	488	12.4	100	95.3	4.57	0.1	0.52
1760	30.0	30.0	40	634	18.4	10	92.3	7.46	0.1	0.60
1770	30.0	30.0	40	634	18.3	25	93.5	6.39	0.1	0.60
1780	30.0	30.0	40	634	18.3	40	94.1	5.70	0.1	0.60
1790	30.0	30.0	40	634	18.3	50	94.4	5.40	0.1	0.60
1800	30.0	30.0	40	634	18.2	60	94.7	5.17	0.1	0.60
1810	30.0	30.0	40	634	18.1	75	94.9	4.96	0.1	0.60
1820	30.0	30.0	40	634	18.1	100	95.1	4.72	0.1	0.60
1830	30.0	30.0	60	720	21.6	10	93.1	6.78	0.1	0.64
1840	30.0	30.0	60	720	21.4	25	93.7	6.16	0.1	0.64
1850	30.0	30.0	60	713	21.2	40	94.2	5.66	0.1	0.64
1860	30.0	30.0	60	713	21.2	50	94.4	5.40	0.1	0.64
1870	30.0	30.0	60	715	21.2	60	94.6	5.20	0.1	0.64
1880	30.0	30.0	60	715	21.1	75	94.8	5.00	0.1	0.64

PRESS (PSIG)

FLOW (LPM)

7.5 Spreadsheet Test Data

Spreadsheet Test Input and Results - O_2 Test No. 7

@now~
@now~
{/ Block;Values}~
~

T0= Minutes		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1	Psig RA-FM1	Temperatures 1	2	3	4
0.1	coldhead on sv2-7 down				61	40						282.6	288.0	288.6	288.9
6.7	ch off				60	40						273.0	284.0	286.0	285.0
13.1	ch on				60	40						271.1	277.3	288.1	280.3
19.3	ch on				59	40						267.0	275.5	287.8	276.8
23.8	ch off				60	40						266.8	274.1	286.0	275.6
31.5	CH on				61	40						269.0	273.4	286.0	273.4
36.5	CH on				61	40						264.0	272.0	285.0	273.0
41.4	off				60	40						257.3	269.7	286.7	271.9
47.2	Start:sv1-8 down CH On				61	40						258.0	266.0	286.0	268.0
54.8	adjust JT 2:1 on P3:P7				54	41						261.0	262.0	285.0	256.0
71.6					54	41						249.7	241.0	285.0	228.0
76.3					56	42						244.0	234.7	283.5	222.7
82.0					53	43						239.4	228.8	282.9	216.5
93.3					52	42						228.8	217.2	281.5	204.9
97.3	sv2-7 up				53	44						225.4	213.8	281.0	201.3
103.3	cycle 4 way valve-OK				53	43						220.0	208.2	283.0	196.0
123.5					54	42						199.5	188.5	284.0	178.6
132.7					53	42						192.7	181.2	275.5	171.3
138.5					53	43						188.2	176.6	274.5	167.0
144.3					52	42						183.8	172.0	273.5	162.5
152.6					49	42						177.1	165.1	271.9	156.4
155.7	sv1-8 down				55	43						175.6	163.7	271.4	153.6
159.5					54	42						173.3	161.3	270.8	151.5
164.3					56	42						170.0	157.6	269.9	148.6
169.3	sv-1-8 jt in 1/100				55	41						165.7	153.3	268.6	144.8
177.9	close JT to 2:1 PR				49	42						160.0	148.5	267.0	139.8
183.0					50	44						157.7	145.5	266.2	136.9
185.5	sv-2-7 up				50	44						156.8	144.5	265.6	134.9
190.3					50	43						153.2	140.7	264.7	132.3
194.4					50	42						151.0	138.3	264.0	130.1
200.4					50	42						146.2	134.1	262.7	126.7
204.9					54	50						143.8	131.5	261.9	124.1
210.1					54	48						140.1	127.7	260.8	121.4
214.3					55	30						136.5	125.1	259.9	119.4
219.9					55	48						132.6	121.8	258.7	116.6
226.6	sv2-7 up				50	51						129.1	118.4	257.3	113.1
231.5					50	52						127.5	116.3	256.4	110.5
237.7					49	50						123.9	112.6	255.2	107.2
244.7					48	50						120.0	108.5	254.2	103.1
256.0	oxygen on				46	51						114.9	103.3	253.6	98.0
262.9	sv1-8 down vent thru fm-1	97.1	NA	96.6	48	48	35.0	10.0	na	20.0	11.0	113.7	101.5	254.0	95.5
271.1		97.3		97.0	47	53	33.0	15.0		36.0	14.0	117.0	104.0	255.0	96.0
285.1		96.7		97.0	49	52	35.0	10.0		35.0	10.0	119.0	105.5	258.0	98.6
295.3		97.0		97.0	45	52	35.0	10.0		35.0	10.0	118.7	105.4	258.5	98.0
304.0		97.2		97.3	49	50	35.0	10.0		35.0	10.0	117.0	104.5	257.1	98.0
310.4		97.2		97.2	48	55	35	10		35	10	115.9	103.9	255.3	97.0
317.1		97.2		97.2	43	52	35	10		34	10	115.7	104.2	253.0	96.0
321.2	sv1-8 down open hv-60	97.2	96.9		48	50	33	12	19	0	11	115.8	104.2	251.8	95.4
331.7	sv2-7 up	97.0	97.5		47	50	33	11	53			114.6	104.5	248.0	94.3
337.4	open hv 50	96.9	95.6		47	54	45	10	54			114.3	104.3	246.7	93.9
341.8		96.3	95.7		42	55	40	12	53			114.0	104.3	245.6	93.3
348.6	sv1-8 down	96.3	96.0		48	53	40	12	53			114.1	104.6	244.5	92.5
356.2	sv2-7 up hv-60 closed	97.5	96.5		40	52	23	14	39			114.4	104.8	242.8	92.8

)-Dec-90

O2 Test 41 7

Spreadsheet Test Input and Results - O_2 Test No. 7 (continued)

@now=

T0= Minutes		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1	Psig RA-FM1	Temperatures 1	2	3	4
361.6	sv1-8 down hv-60 open	96.5			46	52	38	12	53			114.3	104.8	241.6	92.6
369.2	sv2-7 up	96.3	96.8		45	58	40	12	52			114.9	105.3	240.5	92.4
374.1	sv1-8 down	97.5	96.3		38	55	25	16	33			115.2	105.6	239.6	92.3
378.3	sv2-7 up	97.5	96.9		47	55	30	15	40			115.4	105.9	238.8	92.3
384.7	sv1-8 down	96.9	96.1		48	55	35	15	34			115.2	105.7	237.4	92.7
394.5	sv2-7 up	96.5	96.0		45	54	40	15	33			114.9	105.3	235.4	93.0
400.8		97.4	96.6		38	58	33	16	34			114.9	105.3	233.7	92.6
406.0	sv1-8 down	97.1	96.0		47	55	33	15	33			114.9	105.5	232.8	92.8
412.5		97.2	96.3		40	57	33	15	33			115.1	105.4	231.4	92.5
420.3	sv2-7 up	97.1	95.4		47	57	40	15	31			115.8	106.1	230.1	92.5
426.1	hv-60 closed	97.0	95.5	96.7	45	57	35	13	34	12	13	116.7	106.2	227.0	94.0
438.4			95.5	96.5	45	57	35	12	28	14	13	116.0	106.0	226.0	94.0
446.0		97.0	96.0	95.5	43	57	40	14	35	20	20	117.0	106.2	225.2	93.0
452.6		97.0	96.0	95.5	46.0	55.0	45.0	12.0	44.0	20.0	20.0	109.8	106.5	224.0	92.9
459.4	sv1-8 down			95.5	42.0	58.0	35.0	15.0	26.0	17.0	9.0	118.0	107.0	223.3	93.2
467.1				95.8						15.0					
468.6				97.0						18.0					
470.6				97.4						25.0					
474.2				97.9						28.0					
475.3				98.0						28.0					
478.4				98.0						28.0					
480.3				98.5						28.0					
482.3				98.8						29.0					
486.1				99.0						33.0					
487.4				99.5						35.0					
489.3				99.7						40.0					
491.7				100.0						39.0					
493.4				100.2						33.0					
493.6				100.0						30.0					
496.2				100.4						27.0					
498.1				100.0						14.0					
498.2				100.0						11.0					

6-Dec-90

Spreadsheet Test Input and Results - O_2 Test No. 7 (continued)

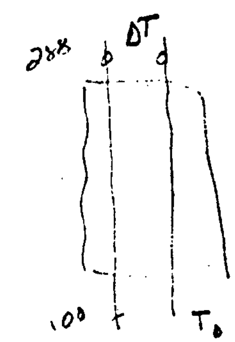
	Time Minutes	6	8	9	P3	P7	L1	L2	Dewar No.	Vaporized Liquid to cool dewars FM4 SCFM	-FM1 Gr/min	FM2 Gr/min	FM6 Gr/min	Liters Dewar1	1.00 Liters Dewar2	Liters L1	Liters L2	Liters Liq withdrawn	L STP withdrw
@now-									0.0	0.0	0.0		0.0						
@now-									0.0	0.0	0.0		0.0						
(/ Block;Values)-									0.0	0.0	0.0		0.0						
-									0.0	0.0	0.0		0.0						
	0.1		288.0	264.0	22.0	29.0			93.0	24.6	0.0		0.0						
	6.7		285.0	259.0	18.0	23.0			90.0	24.2	0.0		0.0						
	13.1		280.0	272.5	22.0	29.0			90.0	24.2	0.0		0.0						
	19.3		276.7	259.3	22.0	30.0			87.0	23.8	0.0		0.0						
	23.8		275.5	268.0	22.0	30.0			90.0	24.2	0.0		0.0						
	31.5		273.3	270.0	22.0	30.0			93.0	24.6	0.0		0.0						
	36.5		272.7	249.0	23.0	30.0			93.0	24.6	0.0		0.0						
	41.4		271.7	242.0	22.0	29.0			90.0	24.2	0.0		0.0						
	47.2		268.0	258.8	20.0	15.0			93.0	24.6	0.0		0.0						
	54.8		252.0	224.0	25.0	12.0			71.1	21.9	0.0		0.0						
	71.5		225.0	201.0	22.0	12.0			71.1	21.9	0.0		0.0						
	76.3		219.6	196.4	24.0	12.0			74.7	23.0	0.0		0.0						
	82.0		213.2	190.1	22.0	12.0			65.3	21.9	0.0		0.0						
	93.3		201.8	178.9	21.0	11.0			64.4	21.3	0.0		0.0						
	97.3		198.2	174.0	30.0	22.0			63.8	22.1	0.0		0.0						
	103.3		193.3	171.9	28.0	20.0			65.3	21.9	0.0		0.0						
	123.5		176.1	155.0	25.0	18.0			69.4	22.1	0.0		0.0						
	132.7		168.7	147.8	23.0	16.0			66.9	21.7	0.0		0.0						
	138.5		164.3	144.0	23.0	16.0			65.3	21.9	0.0		0.0						
	144.3		159.9	139.6	22.0	15.0			64.4	21.3	0.0		0.0						
	152.6		154.1	134.3	24.0	14.0			57.2	20.1	0.0		0.0						
	155.7		150.1	131.3	23.0	20.0			70.3	22.7	0.0		0.0						
	159.5		149.0	130.4	25.0	19.0			69.4	22.1	0.0		0.0						
	164.3		146.1	127.7	23.0	16.0			74.7	23.0	0.0		0.0						
	169.3		142.5	124.0	22.0	16.0			73.8	22.4	0.0		0.0						
	177.9		137.4	118.0	34.0	12.0			57.2	20.1	0.0		0.0						
	183.0		134.4	116.2	27.0	12.0			56.8	20.9	0.0		0.0						
	185.5		132.1	113.2	30.0	19.0			56.8	20.9	0.0		0.0						
	190.3		129.9	112.0	30.0	18.0			58.1	20.7	0.0		0.0						
	194.4		127.5	108.6	30.0	18.0			59.5	20.5	0.0		0.0						
	200.4		124.0	104.7	30.0	18.0			59.5	20.5	0.0		0.0						
	204.9		121.8	103.9	33.0	20.0			58.3	23.7	0.0		0.0						
	210.1		119.5	102.4	34.0	20.0			60.8	23.3	0.0		0.0						
	214.3		117.8	100.6	34.0	20.0			100.8	20.0	0.0		0.0						
	219.9		115.3	98.0	32.0	19.0			63.0	23.7	0.0		0.0						
	226.6		111.8	94.6	36.0	18.0			49.0	22.1	0.0		0.0						
	231.5		109.2	91.7	35.0	17.0			48.1	22.2	0.0		0.0						
	237.7		105.4	88.8	35.0	18.0			48.0	21.5	0.0		0.0						
	244.7		102.6	88.1	34.0	17.0			46.1	21.0	0.0	0.0	0.0						0.0
	256.0		93.1	86.2	34.0	16.0			41.5	20.3	0.0	0.0	0.0						0.0
	262.9		93.9	86.4	35.0	18.0			48.0	20.7	-49.4	0.0	90.6	0.1					26.2
	271.1		94.0	87.5	35.0	20.0			41.7	21.1	-94.0	0.0	92.7	0.3		0.0	0.0		47.1
	285.1		99.0	87.6	35.0	15.0			46.2	21.8	-84.8	0.0	90.6	0.3	0.0	0.0	0.0		45.8
	295.3		98.0	87.6	38.0	10.0			38.9	20.0	-84.8	0.0	90.6	0.3	0.0	0.0	0.0		45.8
	304.0		98.1	87.4	36.0	21.0			48.0	21.5	-84.8	0.0	90.6	0.4	0.0	0.0	0.0		45.8
	310.4		95.9	86.4	33.0	18.0			41.9	21.8	-84.8	0.0	90.6	0.4	0.0	0.0	0.0		45.8
	317.1		95.6	84.9	30.0	16.0			35.6	19.1	-82.4	0.0	90.6	0.5	0.0	0.0	0.0		44.5
	321.2		93.9	87.0	36.0	19.0			46.1	21.0	0.0	35.5	88.4	0.6	0.1	0.0	0.0		0.0
	331.7		94.3	86.6	37.0	24.0			44.2	20.6	0.0	99.1	86.9	0.6	0.3	0.0	0.0		0.0
	337.4		93.8	86.5	35.0	20.0			40.9	21.2	0.0	100.9	116.5	0.6	0.3	0.0	0.0		0.0
	341.8		93.6	86.1	35.0	18.0			32.1	19.1	0.0	99.1	107.2	0.6	0.4	0.0	0.0		0.0
	348.6		94.0	86.5	35.0	20.0			43.5	21.5	0.0	59.1	107.2	0.6	0.4	0.0	0.0		0.0
	356.2		93.3	86.0	30.0	16.0			30.8	17.8	0.0	72.9	63.6	0.6	0.4	0.0	0.0		0.0

5-Dec-90

O2 Test 43 7

Spreadsheet Test Input and Results - O_2 Test No. 7 (continued)

T0= Minutes	6	8	9	P3	P7	L1	L2	Deryn No.	Vaporized Liquid to cool dewars FM4 SCFM	-FM1 Gr/min	FM2 Gr/min	FM6 Gr/min	Liters Dewar1	1.00 Liters Dewar2	Liters L1	Liters L2	Liters Liq withdrawn	L STP withdrw
@now								0.0	0.0	0.0		0.0						
361.6		93.6	86.1	35.0	14.0			40.7	20.5	0.0	99.1	101.8	0.6	0.4	0.0	0.0		0.0
369.2		95.3	87.8	45.0	18.0	0.9	0.9	34.9	20.9	0.0	97.2	107.2	0.6	0.4	0.4	0.4		0.0
374.1		95.7	87.9	45.0	15.0	0.6	0.9	26.3	17.3	0.0	61.7	71.3	0.6	0.5	0.3	0.4		0.0
378.3		95.2	87.4	35.0	20.0	0.8	3.0	40.2	21.4	0.0	74.8	84.3	0.6	0.5	0.3	1.3		0.0
384.7		93.1	87.0	40.0	25.0	1.0	3.6	41.9	21.8	0.0	63.5	98.3	0.6	0.6	0.4	1.5		0.0
394.5		94.8	87.5	40.0	23.0	0.6	4.0	37.5	20.3	0.0	61.7	112.4	0.6	1.0	0.3	1.7		0.0
400.8		93.0	85.7	33.0	16.0	0.5	4.3	24.9	17.6	0.0	63.5	94.1	0.6	1.2	0.2	1.8		0.0
406.0		94.7	87.3	40.0	20.0	0.5	4.5	40.2	21.4	0.0	61.7	92.7	0.6	1.4	0.2	1.9		0.0
412.5		94.4	86.8	39.0	15.0	0.5	4.8	28.1	18.4	0.0	61.7	92.7	0.8	1.5	0.2	2.0		0.0
420.3		95.1	88.1	43.0	23.0	0.5	5.0	38.8	21.7	0.0	57.9	112.4	1.1	1.8	0.2	2.1		0.0
426.1		95.2	87.0			4.0	4.5	35.5	20.7	-30.8	63.5	95.3	1.2	2.0	1.7	1.9	0.1	15.7
438.4		95.0	87.0			4.0	4.6	35.5	20.7	-35.9	52.3	93.8	1.2	2.2	1.7	1.9	0.4	18.3
446.0		95.2	87.9	44.0	17.0	4.0	4.8	32.4	19.8	-57.4	65.4	110.6	1.2	2.4	1.7	2.0	0.7	26.2
452.6		95.4	88.1	43.0	20.0	4.0	4.5	38.5	20.9	-57.4	82.2	120.5	1.1	2.4	1.7	1.9	1.1	26.2
459.4		95.9	88.1	45.0	15.0	4.3	5.0	30.4	19.5	-40.3	48.6	98.3	1.1	2.5	1.8	2.1	1.4	22.2
467.1						4.5	4.5	0.0	0.0	-28.0	0.0	0.0	1.2	2.6	1.9	1.9	1.6	19.6
468.6						4.0	4.0	0.0	0.0	-33.6	0.0	0.0	1.1	2.6	1.7	1.7	1.6	23.5
470.6						3.8	4.0	0.0	0.0	-46.7	0.0	0.0	1.1	2.5	1.6	1.7	1.7	32.7
474.2						3.5	3.5	0.0	0.0	-52.3	0.0	[illegible]	1.0	2.5	1.5	1.5	1.9	36.6
475.3						3.5	3.5	0.0	0.0	-52.3	0.0	0.0	1.0	2.4	1.5	1.5	1.9	36.6
478.4						3.0	3.4	0.0	0.0	-52.3	0.0	0.0	0.9	2.4	1.3	1.4	2.1	36.6
480.3						3.1	3.3	0.0	0.0	-52.3	0.0	0.0	0.9	2.3	1.3	1.4	2.1	36.6
482.3						3.0	3.0	0.0	0.0	-54.2	0.0	0.0	0.8	2.3	1.3	1.3	2.2	37.9
486.1						2.8	2.8	0.0	0.0	-61.7	0.0	0.0	0.7	2.2	1.2	1.2	2.4	43.2
487.4						2.6	2.8	0.0	0.0	-65.4	0.0	0.0	0.7	2.1	1.1	1.2	2.5	45.8
489.3						2.5	2.5	0.0	0.0	-74.8	0.0	0.0	0.6	2.1	1.0	1.0	2.6	52.3
491.7						2.5	2.5	0.0	0.0	-72.9	0.0	0.0	0.6	2.0	1.0	1.0	2.8	51.0
493.4						1.0	2.0	0.0	0.0	-61.7	0.0	0.0	0.5	2.0	0.4	0.8	2.9	43.2
493.6						0.0	2.2	0.0	0.0	-56.1	0.0	0.0	0.5	2.0	0.0	0.9	2.9	39.2
496.2						0.0	2.0	0.0	0.0	-50.5	0.0	0.0	0.4	1.9	0.0	0.8	3.0	35.3
498.1						0.0	1.0	0.0	0.0	-25.2	0.0	0.0	0.4	1.9	0.0	0.4	3.1	18.3
498.2						0.0	0.0	0.0	0.0	-20.6	0.0	0.0	0.4	1.9	0.0	0.0	3.1	14.4



139 g/sec · 5°K

5% · 18% ~ 10°K

139 g/sec · 10°K · .25

4.130 · .25 ~ 32 watts

Heat leak $\frac{37 \text{ watts}}{69}$

5-Dec-90

Spreadsheet Test Input and Results - O_2 Test No. 7 (continued)

@now~
@now~
{/ Block;Values}~
~

Time Minutes	L STP Liq	Effectiveness	O2 Net Flow g/sec
0.1			
6.7			
13.1			
19.3			
23.8			
31.5			
36.5			
41.4			
47.2			
54.8			
71.6			
76.3		0.826	
82.0		0.821	
93.3		0.836	
97.3		0.844	
103.3		0.852	
123.5		0.889	
132.7		0.892	
138.5		0.896	
144.3		0.898	
152.6		0.902	
155.7		0.904	
159.5		0.905	
164.3		0.905	
169.3		0.908	
177.9		0.918	
183.0		0.914	
185.5		0.914	
190.3		0.915	
194.4		0.915	
200.4		0.921	
204.9		0.921	
210.1		0.923	
214.3		0.930	
219.9		0.935	
226.6		0.937	
231.5		0.935	
237.7		0.936	
244.7	0.0	0.936	
256.0	0.0	0.937	
262.9	53.8	0.935	0.69
271.1	-1.7	0.929	-0.02
285.1	7.6	0.926	0.10
295.3	7.6	0.927	0.10
304.0	7.6	0.932	0.10
310.4	7.6	0.935	0.10
317.1	10.8	0.937	0.14
321.2	115.6	0.937	0.88
331.7	113.7	0.945	-0.20
337.4	152.3	0.946	0.26
341.8	140.1	0.947	0.13
348.6	140.1	0.948	0.13
356.2	83.2	0.948	-0.15

-Dec-90

O2 Test 45 7

Spreadsheet Test Input and Results - O_2 Test No. 7 (continued)

	T0= Minutes	L STP Liq	Effectiveness	O2 Net Flow g/sec
@now--				
	361.6	133.1	0.948	0.05
	369.2	140.1	0.947	0.17
	374.1	93.2	0.947	0.16
	378.3	110.2	0.948	0.16
	384.7	128.6	0.948	0.58
	394.5	146.9	0.947	0.84
	400.8	123.0	0.947	0.51
	406.0	121.2	0.948	0.52
	412.5	121.2	0.947	0.52
	420.3	146.9	0.947	0.91
	426.1	84.4	0.942	0.53
	438.4	75.6	0.945	0.69
	446.0	69.6	0.941	0.75
	452.6	82.5	0.982	0.64
	459.4	75.8	0.939	0.83
	467.1			0.00
	468.6			
	470.6			
	474.2			
	475.3			
	478.4			
	480.3			
	482.3			
	486.1			
	487.4			
	489.3			
	491.7			
	493.4			
	493.6			
	496.2			
	498.1			
	499.2			

i-Dec-90

7.6 Test Data

7.6.1 Raw Test Data

02 Test No. 1

est Sept 17 1990

T0= Minutes	14:49 Time		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1	Psig RA-FM1	Temperatures 2	3	4	6	8	9	P3
	15:35																		
0	15:35	sv1-8 warm	95	84		35	50	50	12	75									
0	15:35	LN2 sv-8	82	95									282.0	274.0	268.0	280.0	254.0	182.0	
6	15:41	LN2 sv-8											279.0	282.0	245.8	283.0	225.0	145.0	
12	15:47	LN2 sv-8											270.0	277.0	225.0	283.0	201.0	94.0	
14	15:50	LN2 sv-8											260.0	280.0	209.0	283.0	175.0	87.0	
16	15:51	LN2 & CH sv-8											256.0	281.0	194.0	282.0	124.0	78.9	
20	15:55	LN2 only											179.0	280.0	178.0	282.0	82.0	77.2	
25	16:01	LN2 only											85.0	279.0	167.0	281.0	81.0	78.0	
28	16:03	LN2 only											82.0	278.0	148.0	281.0	82.0	82.0	
33	16:09	LN2 only											81.0	277.0	130.0	281.0	81.0	81.0	
36	16:11	dry N2 sv1-8				48	10						79.0	276.0	124.0	281.0	79.0	80.0	
40	16:15	dry N2 sv1-8				40	10						79.0	275.0	118.0	281.0	80.0	80.0	
46	16:21	O2 on	95.0			70	30	70	0				85.0	273.0	81.2	273.0	75.1	68.9	
49	16:24	O2 on	95.0			58	40	30	10	0		0	84.6	271.0	79.0	267.0	77.6	70.5	27.0
57	16:32	O2 on	97.2			60	40	40	10	0			81.0	268.0	79.0	265.0	77.8	70.4	25.0
60	16:36	sv2-7	95.0			35	55	30	15	0			80.5	254.0	78.0	260.0	74.0	69.0	40.0
66	16:41		93.9	67.0		55	48	50	5	80		5	79.0	233.0	78.0	252.0	73.0	67.0	
68	16:43		94.0	87.5		58	48	25	15	8			78.0	223.0	77.0	240.0	75.0	67.0	40.0
74	16:49	fm-6 oscillating	92.1	67.0		68	45	50	15	62			79.0	202.0	77.0	214.0	73.0	68.8	35.0
77			90.0	67.0		61	45	50	15				79.0	190.0	78.0	194.0	75.0	71.0	
80	16:55		74.7	67.0		60	45	50	18	44			79.0	179.0	79.0	184.0	78.0	71.0	
86	17:01		89.0	67.0		43	48	30	20	44			80.0	176.0	79.0	164.0	77.0	69.0	25.0
89	17:04	sv1-8	90.0	67.0		55	45	100	10	7?			82.0	172.0	81.0	117.0	80.0	70.0	40.0
92	17:07		95.0	67.0		50	50	50	10	0			90.0	165.0	81.0	94.8	77.0	71.0	40.0
99	17:16	hv 60 on	95.1	no flow		50	50	45	18	0	15	9	89.0	158.0	83.0	96.8	82.0	78.0	45.0
101	17:16		96.6	no flow	70	45	50	35	5	0	0	8	87.0	152.0	83.7	99.0	82.0	73.6	50.0
109	17:24	hv-60 on	86.5	no flow	78.00	38	50	40	10	0	8	12	84.9	146.0	82.2	94.0	79.4	75.0	50.0
113	17:28	sv2-7	86.0	no flow	81.00	38	53	50	10	5	44	10	82.9	143.0	82.8	91.1	81.0	73.0	50.0
116	17:31		85.0	no flow	95.00	37	53	40	5	0	36	5	83.0	147.0	83.0	89.0	82.0	73.5	50.0
119	17:34		84.5	no flow	94.90	38	53	35	5	0	36	5	83.7	147.0	84.0	88.5	82.4	74.0	50.0
124	17:39		95.2	no flow	94.91	33	53	40	5	0	33	3	84.4	152.0	84.4	88.0	82.2	74.0	50.0
131	17:47	fm-1 off to pressurize	95.2	no flow	no flow	32	53	30	10	0	0	12	84.4	158.0	84.6	89.5	82.0	73.0	50.0
137	17:52		96.1	89.5	no flow	33	50	23	20	40	0	20	83.0	160.0	83.0	90.0	81.2	73.8	50.0
140	17:55		96.0	87.3	no flow	32	52	25	12	35	0	18	83.0	165.0	83.2	90.9	80.0	72.0	50.0
145	18:01		95.3	88.0	no flow	28	58	50	15	48	0	20	83.6	168.1	82.9	89.9	78.4	71.1	48.0
150	18:06		90.2	91.0	no flow	34	52	38	15	35	0	20	84.5	166.0	84.6	88.6	82.6	74.4	50.0
155	18:10	heater #1 on 50%	91.5	89.2		35	50	35	15	29	0	20	87.0	172.0	84.9	88.6	82.5	74.6	50.0
158	18:13	heater #1 on 50%	78.8	85.1		33	50	50	20	40	0	20	89.9	173.0	84.8	88.2	82.7	76.0	50.0
166	18:21	heater #2 on also	no flow		92.1						12	0							
172	18:27				92.1						12	0							
195	18:50	terminated vacuum			85.8						60	40							

								NTP #/ft3	Coeff	GR/min	GR/liq l	
			Gr/min		Coeff=	186.9	AR	0.1034	4.4521	208.8	1393	1290
			Liq liter=			1142	O2	0.0828	4.9749	186.9	1142	
							Air	0.0749	14.6000	496.2		
			Vaporized Liquid to cool dewar=					1.00				
P7	L1	L2	Derym No.	FM4 SCFM	-FM1 Gr/min	FM6-FM2 Gr/min	Liters Dewar1	Liters Dewar2	Liters L1	Liters L2	Liters Liq withdrawn	L STP withdrw
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			24.5	7.3	0.0							
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			0.0	0.0	0.0	0.0						
			230.4	10.0	0.0	0.0						
			160.0	8.4	0.0	0.0						
			163.3	14.6	0.0	130.8	0.3		0.0	0.0		
19.0			84.1	12.1	0.0	72.7	0.6		0.0	0.0		
19.0			90.0	16.2	0.0	96.9	0.2		0.0	0.0		
28.0			22.3	9.5	0.0	79.7	0.5		0.0	0.0		
	0.4		63.0	20.0	0.0	-41.3	0.6		0.2	0.0		
22.0	1.0		70.1	23.4	0.0	51.5	0.6		0.4	0.0		
25.0	3.5		96.8	26.6	0.0	17.0	0.7		1.5	0.0		
	3.6		82.7	27.7	0.0	132.8	1.0		1.5	0.0		
	3.7		80.0	25.9	0.0	57.1	1.2		1.5	0.0		
20.0	3.8		48.0	20.7	0.0	3.9	1.4		1.6	0.0		
35.0	5.0		67.2	23.1	0.0	111.4	1.5		2.1	0.0		
35.0	6.0		50.0	21.0	0.0	121.1	1.9	0.3	2.5	0.0		
38.0	5.7		50.0	21.0	-28.0	125.4	1.8	0.1	2.4	0.0	0.1	20
38.0	5.6	0.9	40.5	19.4	0.0	75.7	2.0	0.3	2.3	0.4	0.1	0
38.0	5.5	1.0	28.9	16.0	-15.0	96.9	2.5	0.9	2.3	0.4	0.2	10
30.0	5.7	1.0	27.2	13.6	-82.2	111.8	2.9	1.2	2.4	0.4	0.3	58
32.0	5.5	0.8	25.8	16.2	-67.3	86.5	3.2	1.5	2.3	0.3	0.8	47
32.0	5.4	1.0	27.2	16.6	-67.3	75.7	3.0	1.7	2.3	0.4	0.7	47
32.0	5.4	1.0	20.5	14.5	-61.7	86.5	2.8	2.0	2.3	0.4	1.0	43
33.0	5.0	1.0	19.3	14.3	0.0	72.7	2.6	2.6	2.1	0.4	1.2	0
33.0	6.0	1.2	21.8	14.8	0.0	-8.7	2.6	2.7	2.5	0.5	1.2	0
33.0	6.0	1.2	19.7	14.3	0.0	-2.4	2.6	2.7	2.5	0.5	1.2	0
35.0	6.0	4.5	13.5	12.5	0.0	43.1	2.6	2.8	2.5	1.9	1.2	0
38.0	6.0	4.5	22.2	15.2	0.0	35.5	2.6	3.0	2.5	1.9	1.2	0
38.0	6.0	5.5	24.5	15.3	0.0	38.8	2.6	3.1	2.5	2.3	1.2	0
38.0	6.0	5.8	21.8	14.7	0.0	68.8	2.8	3.3	2.5	2.4	1.2	0
	6.0	5.5	0.0	0.0	-22.4	0.0	2.5	3.3	2.5	2.3	1.3	16
	5.5	5.0	0.0	0.0	-22.4	0.0	2.5	3.2	2.3	2.1	1.4	16
	5.0	4.5	0.0		-112.1	0.0	1.8	2.5	2.1	1.9	2.7	78

.529 = R 1.36

$$SCFM = 14.6\left(\frac{P}{14.7}+\right)^{.5}\cdot(1.43)$$

202	18:57		82.9	50	45
209	19:04		85.3	31	15
223	19:19		90.0	28	12
232	19:27		91.2	41	10
234	19:30		93.3	28	10
238	19:33	heaters on 100%	94.1	17	0
245	19:41		93.4	15	0
250	19:45		92.2	8	0

4.4	4.0	0.0	-93.5	0.0	1.5	2.2	1.8	1.7	3.4	65
3.5	3.0	0.0	-57.9	0.0	1.2	2.0	1.5	1.3	3.9	41
3.0	2.0	0.0	-52.3	0.0	0.9	1.6	1.3	0.8	4.6	37
3.3	1.0		-76.6	0.0	0.6	1.4	1.4	0.4	5.0	54
3.1	1.0		-52.3	0.0	0.6	1.3	1.3	0.4	5.2	37
3.0	0.9		-31.8	0.0	0.5	1.2	1.3	0.4	5.3	22
2.5	0.9		-28.0	0.0	0.4	1.1	1.0	0.4	5.5	20
0.5	0.7		-15.0	0.0	0.4	1.1	0.2	0.3	5.6	10

O2 Test No. 2

est Sept 20 1980

T0-Minutes	14 46 Time		%O2 FM6 air-dry	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1	Psig RA-FM1	Temperatures 2	3	4	6	8	9	P3	P7	L1	L2	Gram Liq Nitro-Delta P Flo Vaporized Oxygen No
																							0.0
	14 37																						0.0
0	14 37	LN2 av-8																					0.0
2	14 40	ch on											288.0	287.0	285.0	288.0	280.0	236.0					0.0
11	14 48	CH on											285.0	287.0	265.0	288.0	252.0	99.0					0.0
19	14 58	o2 on to drain out	85					40					238.0	285.0	205.0	283.0	83.0	78.4					0.0
22	15 00	o2 on to drain out	80					25					280.0	280.0	181.0	273.0	83.0	77.0					0.0
26	15 03	o2 on to drain out	85					25	0	0			83.0	281.0	165.0	265.0	83.0	77.0					0.0
29	15 06	o2 on to drain out, O2 off	92					0	0				82.0	281.0	152.0	253.0	83.6	78.0					0.0
25	15 07	O2 off LN2 on	92										79.0	277.0	116.0	230.0	68.0	68.9					0.0
46	15 23	air on hv 50 open				35	55	25	0	0			80.8	127.0	77.0	203.0	60.0	59.6					22.3
67	15 44	av1-8				30	50	35	0	15			81.0	97.0	73.0	199.0	68.0	66.0			0.0		18.0
76	15 53	CH #1 off	88			35	50	25	0	40			86.0	94.5	73.8	191.0	66.0	60.0			0.0		24.5
79	15 57		95	78		30	50	30	10	40			74.0	94.4	74.0	184.0	70.0	69.0			0.0		18.0
83	16 01	av2-7	93.6	78.0		30	50	28	13	30			75.0	97.0	75.0	167.0	68.0	65.0					15.0
88	16 05		95.2	77.3		30	50	35	15	30			75.0	92.0	75.3	151.0	72.6	65.6					18.0
90	16 08		93.0	74.5		30	50	38	10	24			75.8	91.8	77.0	117.0	72.8	65.8					18.0
93	16 10	Liquid	93.5	75.0		30	50	32	15	35			76.0	92.0	76.0	95.0	73.0	66.1			2.0		18.0
96	16 13		93.8	76.8		30	50	40	15	60			76.3	92.4	76.0	93.8	73.4	66.0			2.5		18.0
101	16 18	Inc O2	86.0	84.0		30	50	40	17	50			77.0	93.0	78.0	86.0	74.0	66.0			3.0		18.0
108	16 25		94.5	91.5		20	50	20	10	38			77.0	95.0	76.9	85.0	75.0	66.0			3.8		8.0
108	16 25	av1-8	95.7	91.0		33	50	29	10	28			78.0	96.3	77.5	84.0	76.0	68.0			3.9		18.0
110	16 27		96.0	94.0		35	50	45	7	24			80.0	97.5	77.0	82.8	76.8	69.0			4.0		24.5
114	16 31		95.7	95.0		35	50	45	7	20			81.0	99.8	79.6	83.3	77.0	70.0			4.6		24.5
119			93.4	92.6		35	50	50	5	20			82.5	100.7	80.0	83.6	77.8	70.9			4.8		24.5
121	10 38	AIR of CH off	95.5	92.6		33	50	45	5	18			88.0	98.0	82.0	86.0	78.4	71.6			5.0		21.8
123	16 41	HV-80 open FM-1	96.3		69			50	5	33	35	5	89.0	95.6	84.2	87.7	80.0	83.0			5.3		0.0
133	16 51	HV-80 open FM-1	96.0	79.0	67			47	0	8	35	5	88.0	92.7	86.8	88.7	86.4	88.0			5.5	0.5	0.0
138	16 55	HV-80 open FM-1	95.9	79.8	70.00			35	5	15	38	5	.90	94.2	88.7	90.8	88.7	90.8			5.5	0.5	0.0
150	17 07	HV-80 open FM-1	95.6		80.00			40	5	20	44	10	91.8	110.0	89.0	95.3	88.9	95.0			5.5	0.5	0.0
154	17 11	HV-80 open FM-1	75.8	88.9	86.30			55	10	38	44	8	94.5	118.0	91.5	99.5	99.9	105.0			5.5	0.5	0.0
159	17 16	HV-60 open FM-1	93.8	92.5	86.50			44	8	35	40	8	97.5	127.0	92.9	101.0	93.8	107.0			5.5	0.5	0.0
175	17 32	HV-80 open FM-1	95.9	95.8	88.60			38	5	24	34	5	104.0	159.0	101.0	112.5	106.2	124.0			4.5	0.5	0.0
184	17 41	HV-80 open FM-1	93.9	95.5	88.7			40	7	30	38	5	109.0	167.0	104.7	113.8	107.6	126.0			4.5	0.5	0.0
193	17 50	closed fm-1	96.3	95.8	89.0			25	7	44	0	30	113.0	176.0	110.8	120.6	115.0	135.0			4.4	0.5	0.0
202	17 59	open fm-1	96.4	95.8	90.0			30	7	40	15	20	120.0	196.0	120.0	125.0	116.5	135.0			4.3	0.5	0.0
217	18 14			95.2	91.2			35	10	50	10	20	124.0	201.0	126.0	132.0	124.0	144.0			4.5	0.5	0.0
225	18 22		95.7	95.6	94.8			39	4	20	30	0	128.0	210.0	129.6	137.3	128.0	147.0			3.8	0.5	0.0
232	18 29	raise dewar #1 pressure	96.4	95.6	95.44			25	6	5	35	5	130.0	215.0	134.0	137.7	135.0	151.0			3.6		0.0
240			96.0	95.8	95.00			25	0				135.0	220.0	140.0	140.0	145.0	155.0			3.5		0.0
255	18 53			96.0	95.1			20	8	28	5	25	140.0	223.0	152.0	146.0	153.0	161.0			3.4		0.0
257	19 04			98.0	98.0			25	9	38	5	20	144	230	154	156					3.2		0.0
274	19 11	Broke Vac			96.6						25	0	155	233	160	160					3.0	0.5	0.0
281	19 19				96.6						10		160	235	170	170					2.0		0.0
287	19 24				96.7						0		180	238	189	189					0.0		0.0

				NTP #/ft3	Coeff	GR/min	GR/liq l	
	Coeff=	186.9	AR	0.1034	4.4521	208.8	1393	1290
		1142	O2	0.0828	4.9749	186.9	1142	
8=	3.80		Air	0.0749	14.6000	-96.2		
Liquid to cool dewar=				1.00				
FM4 SCFM	-FM1 Gr/min	FM6-FM2 Gr/min	Liters Dewar1	Liters Dewar2	Liters L1	Liters L2	Liters Liq withdrawn	L STP withdrw
0.0	0.0	0.0						
0.0	0.0	0.0						
0.0	0.0	0.0						
0.0	0.0	0.0						
0.0	0.0	0.0						
0.0	0.0	83.9						
0.0	0.0	52.4						
0.0	0.0	52.4						
0.0	0.0	0.0						
0.0	0.0	0.0						
7.3	0.0	52.4	0.5		0.0			
6.3	0.0	45.3	1.4		0.0			
7.3	0.0	-22.3	1.5		0.0			
6.3	0.0	3.3	1.4		0.0			
13.6	0.0	20.5	1.5		0.0	0.0		
13.1	0.0	42.7	1.6		0.0	0.0		
13.1	0.0	54.0	1.7		0.0	0.0		
13.1	0.0	24.9	1.8		0.8	0.0		
13.1	0.0	0.7	1.9		1.0	0.0		
13.1	0.0	22.7	1.9		1.3	0.0		
8.8	0.0	-19.0	1.9		1.6	0.0		
13.1	0.0	23.1	1.9		1.8	0.0		
15.3	0.0	65.9	2.0		1.7	0.0		
15.3	0.0	73.4	2.2		2.0	0.0		
15.3	0.0	80.8	2.6		2.0	0.0		
14.5	0.0	72.7	2.7	0.1	2.1	0.0		
0.0	-75.7	56.5	2.7	0.3	2.2	0.0	0.1	46
0.0	-75.7	83.6	2.7	0.2	2.3	0.2	0.8	46
0.0	-82.2	54.7	2.7	0.2	2.3	0.2	1.1	50
0.0	-106.6	57.1	2.3	0.2	2.3	0.2	2.1	58
0.0	-102.2	72.1	2.1	0.2	2.3	0.2	2.4	56
0.0	-92.9	45.0	1.9	0.2	2.3	0.2	2.9	52
0.0	-73.6	44.9	1.4	0.2	1.9	0.2	4.0	44
0.0	-82.2	42.4	1.1	0.2	1.9	0.2	4.7	50
0.0	0.0	-20.7	0.9	0.2	1.8	0.2	5.0	0
0.0	-43.1	-0.9	0.7	0.2	1.8	0.2	5.1	20
0.0	-28.7	-2.4	0.2	0.2	1.9	0.2	5.6	13
0.0	-56.1	52.8	0.0	0.2	1.6	0.2	5.9	39
0.0	-75.7	51.0	-0.1	0.2	1.5	0.0	6.3	46
0.0	0.0	52.4	0.0	0.2	1.5	0.0	6.6	0
0.0	-15.4	-2.1	0.3	0.2	1.4	0.0	6.7	7
0.0	-14.4	-7.1	0.1	0.2	1.3	0.0	6.8	7
	-46.7	0.0	-0.1	0.2	1.3	0.2	7.0	33
	-18.7	0.0	-0.3	0.2	0.8	0.0	7.2	13
	0.0	0.0	-0.4	0.2	0.0	0.0	7.3	0

Oct 4 1990

T0-Minutes	14:25 Time		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	O FM4	Psig Ra2	O FM-6	Psig Ra5	O FM2	O FM1	Psig RA-FM1	Temperatures 2	3	4	6	8	9	P3	P7	L1	L2	Gr/min Liq liter-Delta P FM-Vaporized Derym No.
																							0.0
	14:25																						0.0
0	14:25	CH + N2 only				30	50						265.0	267.0	283.0	286.0	272.0	210.0					18.0
9	14:34	CH + N2 only				30	40						257.0	266.0	240.0	266.9	230.8	174.0					22.5
12	14:37	CH + N2 only				29	39						253.0	265.0	222.0	286.0	221.0	172.0					21.6
16	14:41	LN2 + CH											238.0	265.0	205.0	283.0	212.0	161.0					0.0
25		LN2 + CH											234.0	284.0	207.0	285.0	195.0	98.0					0.0
31	14:56	LN2 + CH											216.0	282.0	182.0	285.0	141.0	90.0					0.0
33	14:56	n2 +ch				34	42						206.0	282.0	169.0	284.0	90.0	84.0					27.5
38		n2 +ch				35	42						185.0	281.0	156.0	284.0	86.0	84.0					29.2
40		Air on				30	55	30	10	38			97.0	280.0	132.0	283.0	97.0	90.4					16.4
43	15:08	ev1-8	93.70			25	60	33	15	16			97.6	275.0	123.0	279.0	96.0	90.4			0.0		10.4
45		CH #1 off	88.00	91.00				30													0.0		0.0
48	15:13	ev-1	94.20	94.00		20	60	30	14	22			97.0	278.0	118.0	269.0	95.0	90.0			0.0		6.7
51	15:16	ev-1	95.80	94.40				30	11				97.0	277.0	116.0	263.0	97.0	90.0					0.0
53	15:18	ev-1	96.00	95.22		20	60	30	11	35			97.4	276.0	114.0	251.0	97.1	89.9					6.7
56	15:21	ev 1-8	96.00	95.90		20	60	30	11	35			97.0	278.0	112.0	238.0	96.9	89.5					6.7
61	15:26	bag #1 MSOG Supply	96.00	94.50		22	60	30	11	35			96.0	275.0	111.0	229.0	96.7	89.4			0.5		6.1
64	15:29	ev 2-7	94.56	94.00		25	60	30	10	24			97.0	273.0	109.0	210.0	96.7	89.0			0.5		10.4
69	15:34	ev 2-7	95.66	94.00		20	62	30	15	26			97.0	273.0	108.0	202.0	96.9	89.6			0.6		6.5
72	15:37	ev 2-7	95.60	95.00		18	62	30	15	25			96.0	271.0	107.8	192.0	96.0	89.0			0.7		5.2
78	15:43	ev 1-8	95.60	95.40		15	65	40	10	80			98.0	270.0	108.0	175.0	97.0	84.0			0.7		3.5
82	15:47	ev 1-8	96.00	95.80		14	64	30	10	50			97.0	268.0	106.0	169.0	96.7	89.0			0.8		3.1
85	15:50	ev 2-7	96.10	96.00		15	65	30	10	45			97.0	268.0	106.0	165.0	97.0	89.0			0.9		3.5
88	15:53		96.00	96.00		16	64	35	12	40			97.8	266.0	105.0	150.0	97.0	89.0			1.0		4.0
92	15:57		95.50	95.80		30	65	30	13	54			97.8	266.0	105.0	155.0	97.3	89.0			3.0		13.8
94	15:59	ev1-8	95.50	95.00		15	65	26	10	60			97.0	264.0	102.0	149.0	97.2	90.3			4.0		3.5
100	16:06	ev 1-8	96.48	95.60		15	10	35	8	60			98.0	262.0	104.0	143.0	97.8	89.0			4.5		22.5
106	16:11		95.80	95.80		33	10	35	10	44			97.0	260.0	101.0	138.0	97.0	89.0			4.5		108.9
114	16:19		95.60	95.60		18	65	20	8	38			96.2	259.0	99.9	136.0	97.6	89.0					5.0
121	16:26		96.00	95.50		15	69	24	5	18			94.5	258.0	99.7	134.0	97.0	88.6					3.3
124	16:29		96.60	96.10		20	70	30	10	25			95.4	256.0	98.0	131.0	95.0	85.6			3.9		5.7
135	16:41	all off							14				89.9	254.0	95.5	129.0	86.0	86.0			4.0		0.0
142	16:47								15		20												0.0
152	16:57				95.00						10												0.0
154	16:59				95.40						10												0.0
155	17:00				96.30						10												0.0
158		bag #2 sample fm -1		64	95.40						10												0.0
161	17:06	raise dewer #1 pressure			95.20						5												0.0
0					95.00						5												0.0
0																							0.0
0																							0.0
0		Broke Vac																					0.0
0																							0.0
0											0												0.0

				NTP #/ft3	Coeff	GR/min	GR/liq l	
	Coeff=	186.6	AR	0.1034	4.4521	208.8	1393	1290
		1142	O2	0.0828	4.9749	186.9	1142	
6=	3.80		Air	0.0749	14.6000	496.2		
Liquid to cool dewar=				1.00				
FM4	-FM1	FM6-FM2	Liters	Liters	Liters	Liters	Liters Liq	L STP
SCFM	Gr/min	Gr/min	Dewar1	Dewar2	L1	L2	withdrawn	withdrw
0.0	0.0	0.0						
0.0	0.0	0.0						
6.3	0.0	0.0						
6.3	0.0	0.0						
6.1	0.0	0.0						
0.0	0.0	0.0						
0.0	0.0	0.0						
0.0	0.0	0.0						
13.6	0.0	0.0						
7.3	0.0	0.0						
6.3	0.0	78.1	0.1		0.0			
5.2	0.0	93.1	0.3		0.0			
0.0	0.0	62.9	0.4		0.0			
8.2	0.0	83.4	0.6		0.0			
0.0	0.0	79.4	0.9		0.0	0.0		
9.4	0.0	79.4	1.0		0.0	0.0		
4.2	0.0	79.4	1.2		0.0	0.0		
10.4	0.0	79.4	1.5		0.2	0.0		
5.2	0.0	78.1	1.7		0.2	0.0		
9.4	0.0	84.6	2.1		0.3	0.0		
8.5	0.0	84.6	2.3		0.3	0.0		
7.1	0.0	104.1	2.8		0.3	0.0		
6.6	0.0	78.1	3.2		0.3	0.0		
7.2	0.0	78.1	3.3		0.4	0.0		
7.6	0.0	94.2	3.6		0.4	0.0		
14.6	0.0	82.1	3.8		1.3	0.0		
7.2	0.0	66.6	4.0		1.7	0.0	0.0	0
7.3	0.0	87.8	4.4		1.9	0.0	0.0	0
15.9	0.0	91.1	4.9	0.2	1.9	0.0	0.0	0
8.8	0.0	50.2	5.4	0.2	0.0	0.0	0.0	0
7.3	0.0	56.7	5.7	0.2	0.0	0.0	0.0	0
5.4	0.0	78.1	5.9	0.2	1.6	0.0	0.0	0
0.0	0.0	0.0	6.3	0.2	1.7	0.0	0.0	0
0.0	-37.4	0.0	6.2	0.2	0.0	0.0	0.1	26
0.0	-18.7	0.0	5.9	0.2	0.0	0.0	0.3	13
0.0	-18.7	0.0	5.9	0.2	0.0	0.0	0.4	13
0.0	-18.7	0.0	5.9	0.2	0.0	0.0	0.4	13
0.0	-18.7	0.0	5.8	0.2	0.0	0.0	0.4	13
0.0	-9.3	0.0	5.8	0.2	0.0	0.0	0.5	7
0.0	-9.3	0.0	7.1	0.2	0.0	0.0	-0.8	7
0.0	0.0	0.0	7.1	0.2	0.0	0.0	-0.8	0
0.0	0.0	0.0	7.1	0.2	0.0	0.0	-0.8	0
	0.0	0.0	7.1	0.2	0.0	0.0	-0.8	0
	0.0	0.0	7.1	0.2	0.0	0.0	-0.8	0
	0.0	0.0	7.1	0.2	0.0	0.0	-0.8	0

Oct 23
Oct 4 1990

T0- Minutes	14:25 Time		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1	Psig RA-FM1	Temperatures 1	2	3	4	6	8	9	P5	P4	L1
	10:33																					
-47													144.0	130.0	272.0	118.0	282.0	118.0	98.0			
-35						37	52						142.0	129.0	272.0	118.0	282.0	116.0	86.0			
-32						34	52						132.0	131.0	272.0	119.0	282.0	116.0	107.0			
-25													134.0	131.0	272.0	122.9	282.0	122.9	130.6			
-24						31	52						137.5	133.6	272.0	126.0	282.0	126.0	127.0			
-21						29	55						134.0	131.0	272.0	122.0	282.0	122.0	130.0			
-19						28	55						137.2	137.5	272.0	129.5	282.0	129.0	129.0			
-17						30	58						137.0	138.0	272.0	132.0	282.0	129.0	130.0			
-0	10:32	ev1-8				33	55						139.0	132.0	272.0	118.0	282.0	117.0	94.5			
6	10:38	ev1-8				35	55						138.0	128.0	272.0	113.0	282.0	112.0	91.1			
15	10:48	ev1-8 O2 on to purge				33	55						136.1	123.8	270.0	111.0	282.0	110.0	90.7			
16	10:49	ev1-8				33	55						133.0	121.0	269.0	105.0	282.0	105.0	90.0			
18	10:51	start O2 HV50	96.00			34	55						129.0	120.0	268.0	104.0	282.0	101.0	89.7			
23	10:55		96.70			32	54	20	12	40			124.0	111.0	267.0	98.0	278.0	97.0	89.0			
26	10:59		96.90	96.50		28	55	20	12	39			124.0	111.0	267.0	96.0	271.0	97.5	90.0			
31	11:04		96.70	96.11		25	58	25	12	38			124.0	111.0	267.0	95.9	265.0	97.5	92.0			
33	11:06	CH off to derym	96.90	96.07		24	59	20	10	35			124.8	112.0	266.0	95.3	257.0	98.0	97.0			
36	11:09		97.00	96.07		23	60	20	14	38			125.0	112.0	265.0	98.0	240.0	105.0	116.0			
41	11:13	ev2-8	97.10	96.13		27	58	20	12	35			125.4	116.0	265.0	104.0	232.0	109.0	112.0			
46	11:18	ev2-8				23	58	22	12	34			125.0	119.0	264.0	115.0	222.0	115.0	114.0			
52	11:25	ev2-8				22	60	23	12	34			125.0	120.0	264.0	123.0	210.0	121.0	116.0			
54	11:27	ev1-8 CH on	97.32			23	59	23	12	34			127.0	129.0	262.0	123.0	203.0	121.0	118.0			
62	11:35	ev1-8	96.00			27	59	24	10	30			140.7	134.8	260.0	119.0	192.0	119.0	94.0			
71	11:44	O2 off to cooldown	97.60	97.22		28	56	25	15	40			141.0	136.0	260.0	114.0	185.0	114.0	91.0			
74	11:47	open JT alittle	96.70	97.22		34	55	5	10	20			139.0	127.0	258.0	112.0	183.0	113.0	91.9			
81	11:54		97.20	97.22		50	50	9	14	18			133.0	119.0	258.0	108.0	179.0	109.0	91.0			
86	11:58		97.00	97.20		50	45	13	8	0			130.0	116.0	257.0	108.0	178.0	108.0	91.0			
87	12:00		97.00	97.00		49	45	5	12	0			128.0	114.0	256.0	107.0	176.0	106.0	89.0			
96	12:09	derym ev2-7	97.00	97.00		49	45						127.0	121.0	252.0	114.0	173.0	112.0	98.0	25.0		20
105	12:18	n ev1-8	97.00	97.00		48	48	8	9	0			125.0	121.0	252.0	113.0	173.0	111.0	91.0	30.0	8.0	18
108	12:21		97.56	97.00		45	50	5	15	25			126.5	119.0	254.0	111.4	173.0	109.0	91.0	29.0	8.0	21
119	12:32		97.56	97.00		55	45	15	10	23			125.0	116.7	257.0	108.9	172.8	106.5	84.2	20.0	5.0	25
120	12:33	derym ev 2-7	97.40	97.30		53	45	15	10	22			115.0	118.0	253.0	110.0	170.0	108.0	109.0	30.0	10.0	15
127	12:40	ev 2-7	97.70	97.00		54	45	20	10	35			116.0	120.0	254.0	117.0	167.0	115.0	116.0	22.0	35.0	23
132	12:45	ev 2-7 Cal w Math bottle 95.7	97.70	97.00		53	44	15	10	22			125.0	129.0	251.0	125.0	165.0	126.0	125.0	18.0	37.0	26
144	12:57	1 ch on	97.60	97.00		58	45	15	10	15			136.0	140.0	250.0	136.0	163.0	134.0	125.0	12.0	38.0	33
143	13:01	ev 1-8	97.60	97.00		50	45	15	10	16			137.0	142.0	250.0	136.0	163.0	135.0	111.0	38.0	10.0	7
154	13:07		97.00	97.00		49	55	5	10	0			142.0	139.0	250.0	132.0	164.0	130.0	105.0	35.0	10.0	20
164	13:17		97.00	97.00		55	43						137.0	133.0	248.0	122.0	166.0	119.0	96.7	32.0	10.0	11
171	13:24		97.00	97.00		58	45						130.6	121.5	248.0	116.0	169.0	115.0	92.0			45
178	13:30	reduced flow for cooldown	97.00	97.00		38	15						126.0	117.0	248.0	111.0	168.0	107.0	60.0	10.0	0.0	5
184	13:36	o2 on	97.50	97.00		50	30	20	10	0			121.6	111.0	246.0	99.6	175.0	89.0	83.0	20.0	5.0	10
188	13:41		97.50	97.00		48	30	21	12				118.0	108.5	246.0	96.6	176.0	88.0	81.0	15.0	0.0	15
195	13:48		97.6	97.0		35	35	20	15	0			117.0	108.3	246.0	94.2	177.0	87.0	80.0	12.0		23
204	13:57		97.6	97.0		35	50	20	18				116.8	108.0	246.0	92.4	178.0	87.7	81.0	17.0	4.0	33
209	14:02		97.0	96.5		32	50	20	15	55			116.5	107.5	246.0	91.9	168.0	87.4	80.4	12.0	0.0	38
212	14:05	derym	97.7	97.0		28	53	20	15	45			116.0	107.0	244.0	91.0	159.0	86.0	79.0			53

215			97.7	96.0		55	45	10	20	70		104.0	108.0	243.0	96.0	149.0	93.0	94.0	30 0	40 0	15	
218		2 CH on deryn	97.7	97.0		55	45					99.0	108 0	243.0	98.6	145.9	97.0	97 0	25 0	38 0	20	
220			97.7	97.0		55	45					96.4	109.0	234.0	101.0	142.0	99 0	99 0	26 0	10.0	19	
224	14:17	sv1-8	97.2	98.0		55	45	20	12	13		100.0	108.0	238.0	100 0	140 0	95 0	92.0	28.0	10 0	17	
229	14:21	sv1-8	97.9	96.3		53	45	20	14	5		108.2	108.5	238 0	97.0	139 0	91.5	91.6	28 0	10 0	17	0.3
232	14:25		97.7	98.0		53	48	25	15	0		108 0	107.0	242.0	96.0	137 0	91.0	85.0	29 0	10 0	19	0 3
237	14:29		97.0	98.0		50	48	20	20	10		107 0	105.0	242.0	95 0	133 0	90.0	85 0			48	0 4
240	14:33		97.7	96.0		49	48	20	18	12		112.0	105 3	241.0	95.4	134.0	91.0	84 8	25 0	5 0	23	0 5
246	14:38		97.0	97.0		35	50	20	15	35		109 0	105.0	238.0	95.0	125 0	88 0	81.0			50	1 0
249	14:42		97.0	96.0		22	58	20	15	10		114.0	106 0	240 0	93 5	108 0	84.9	79.0	8 0		50	4.0
252	14:45	off			95.9						30										0	3 5
256	14:52				96.2						28										0	3 5
259	14:52				96.5						30										0	3 5
261	14:54				97.0						30										0	3 5
262	14:55				97.1						34										0	3 5
290					97.0						10										0	0 0
300																					0	
24-Oct			Heat Exchanger Design																		0	
																					0	
																					0	
																					0	
																					ERR	
																					ERR	

							Cp eqivalents			P(atm)	J/gram-K	J/gram	
04:16 PM		Ua-HX1b		0.72		hx-1b	o2	13 to 102 k		5.00	1.00		
file:02hxlq		UA-HX1c w/k		16.73	w/k	hx-1c	Liq O2	latent heat		5.00	199.70		
				Heat Leak Effect		hx-1a	o2	300 to 113		5.00	0.94		
				Qleak	cE	hx-1a	air	300 to 113		5.00	1.04	194.29	
		H1a		21.40	0.01	o-hd	air	113 to 84		5 to 1	0.87	25.36	
		H1b			0.00	hx-1c	air	84 to 94		1.30	1.04	10.45	
		H1c			0.00	hx-1a &1b	air	94 to 300		1.3	1.02	210.33	
		Cold H		5.00	ERR								
				26.40									
					Input	Tliq=	99						
	O2		Air										
	Flow g/sec		Flow g/sec		Iterator		UA vapor	NTU LIQ	1C + 1B				
E-HX-1	20.00%		13.41	O(liq)		Ta1			E	Iterator	Tlow K	T out	T out
Meter Reading	4.3%		56.6%	watts								Liquif	Vapor
PSIG+	18.00		40.00										
Test O2	105.51												
0.97	0.66		13.41	131.80	113.75	113.76	0.48	1.21	0.69	85.41	85.41	94.81	95.51
0.97	0.15		13.41	29.96	110.00	109.95	0.20	1.23	0.70	95.00	95.94	98.08	98.19
0.96	0.20		13.41	39.94	115.42	111.98	0.16	1.23	0.70	85.37	94.92	97.77	98.01
								REVERSE FLOW					
				COLD HEAD HX					106.15	29.96	100.43	3.24%	
			Q o2	Q	Tch			Tout	T@ sw6	watts	T @ sw4	FM-6	
			watts Total	watts	K	E	NTU	warm					
Forward Flow HX SI			256.24	332.46	77.74	0.80	1.59	293.46					

					NTP #/RG	Coeff	GR/min	GR/liq l	
Gr/min		Coeff=	188.9	AR	0.1034	4.4521	208.8	1383	1280
Liq liter=			1142	O2	0.0828	4.9740	188.9	1142	
Delta P FM-6=		3.80		Air	0.0749	14.6000	496.2		
Vaporized Liquid to cool dewar=					1.00				

L2 Derym No.	FM4 SCFM	-FM1 Gr/min	FM6-FM2 Gr/min	Liters Dewar1	Liters Dewar2	Liters L1	Liters L2	Liters Liq withdrawn	L STP withdrw
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
0.0	0.0	0.0	0.0						
26.3	7.7	0.0	0.0						
22.2	7.1	0.0	0.0						
0.0	0.0	0.0	0.0						
18.5	6.5	0.0	0.0						
15.3	12.9	0.0	0.0						
14.3	12.5	0.0	0.0						
15.5	6.3	0.0	0.0			0.0			
19.8	14.7	0.0	0.0			0.0			
22.3	15.9	0.0	0.0			0.0			
19.8	15.0	0.0	0.0			0.0			
19.8	15.3	0.0	0.0			0.0	0.0		
21.0	15.5	0.0	0.0			0.0	0.0		
19.0	14.5	0.0	53.6			0.0	0.0		
14.3	12.7	0.0	53.8			0.0	0.0		
10.8	11.4	0.0	67.3			0.0	0.0		
9.8	10.9	0.0	52.0			0.0	0.0		
8.8	10.4	0.0	55.6			0.0	0.0		
12.6	12.3	0.0	53.8			0.0	0.0		
9.1	10.7	0.0	58.2			0.0	0.0		
8.1	10.3	0.0	61.9			0.0	0.0		
9.0	10.8	0.0	61.9			0.0	0.0		
12.4	12.5	0.0	62.5			0.0	0.0		
14.0	13.0	0.0	70.5			0.0	0.0	0.0	0
21.0	16.0	0.0	13.0			0.0	0.0	0.0	0
50.0	23.4	0.0	25.0			0.0	0.0	0.0	0
55.6	23.4	0.0	32.6			0.0	0.0	0.0	0
53.4	22.4	0.0	13.5			0.0	0.0	0.0	0
53.4	22.3	0.0	0.0			0.0	0.0	0.0	0
48.0	21.0	0.0	20.5			0.0	0.0	0.0	0
40.5	18.9	0.0	14.1			0.0	0.0	0.0	0
67.2	23.1	0.0	39.0			0.0	0.0	0.0	0
62.4	22.3	0.0	39.0			0.0	0.0	0.0	0
64.8	23.3	0.0	52.0			0.0	0.0	0.0	0
63.8	23.2	0.0	39.0			0.0	0.0	0.0	0
74.8	2-.4	0.0	39.0			0.0	0.0	0.0	0
55.6	21.0	0.0	39.0			0.0	0.0	0.0	0
43.7	20.6	0.0	13.0			0.0	0.0	0.0	0.0
70.3	22.9	0.0	0.0	0.0		0.0	0.0	0.0	0.0
74.8	24.4	0.0	0.0	0.0		0.0	0.0	0.0	0.0
96.3	16.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0
83.3	22.7	0.0	52.0	0.0		0.0	0.0	0.0	0.0
76.8	19.9	0.0	56.5	0.0		0.0	0.0	0.0	0.0
35.0	14.7	0.0	56.4	0.0		0.0	0.0	0.0	0.0
24.5	10.4	0.0	58.9	0.0		0.0	0.0	0.0	0.0
20.5	11.7	0.0	56.4	0.0		0.0	0.0	0.0	0.0
14.8	10.2	0.0	56.4	0.0		0.0	0.0	0.0	0.0

67.2	21.1	0.0	30.2	0.0	0.0	0.0	0.0	0.0
67.2	24.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
67.2	24.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
67.2	24.8	0.0	53.8	0.0	0.0	0.0	0.0	0.0
62.4	22.3	0.0	55.6	0.2	0.1	0.0	0.0	0.0
58.5	22.3	0.0	70.5	0.4	0.1	0.0	0.0	0.0
52.1	21.0	0.0	60.5	0.7	0.2	0.0	0.0	0.0
50.0	20.6	0.0	58.9	0.8	0.2	0.0	0.0	0.0
24.5	14.7	0.0	54.4	1.1	0.4	0.0	0.0	0.0
8.3	9.5	0.0	56.4	1.3	1.7	0.0	0.0	0.0
0.0	0.0	-56.1	0.0	1.3	1.5	0.0	0.1	39.2
0.0	0.0	-52.3	0.0	0.9	1.5	0.0	0.4	36.6
0.0	0.0	-56.1	0.0	0.9	1.5	0.0	0.4	39.2
0.0	0.0	-56.1	0.0	0.9	1.5	0.0	0.5	39.2
0.0	0.0	-63.5	0.0	0.8	1.5	0.0	0.6	44.5
0.0	0.0	-18.7	0.0		0.0	0.0	1.6	13.1

O2 TEST # 5.WQ?
NOV 30

1990

T0= Minutes	14:25 Time		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1
	9.77										
2	9.80					55	33				
16	10.03					53	30				
19	10.08					53	30				
23	10.15					52	30				
26	10.20					53	30				
34	10.33					53	30				
36	10.37					52	30				
39	10.42					50	30				
42	10.47					53	30				
46	10.53					53	30				
52	10.63					52	30				
64	10.83					53	30				
69	10.92					53	30				
74	11.00					51	30				
79	11.08					52	30				
84	11.17					52	30				
89	11.25					52	30				
94	11.33					52	30				
99	11.42					52	30				
104	11.50					52	30				
109	11.58					52	30				
114	11.67					52	30				
119	11.75					52	30				
129	11.92					44	30				
134	12.00					44	32				
144	12.17					44	32				
154	12.33					46	31				
164	12.50					46	31				
174	12.67					45	32				
179	12.75					47	32				
184	12.83					47	30				
204	1.17					47	30				
214	1.33					48	30				
224	1.50					48	32				
242	1.80		95.70	95.70		45	30	25	15	38	
248	1.90		95	95		46	30	25	15	38	
254	2.00	Bag Sample #1 @ FM-6	95.5/ 95.40	94.70		48	31	25	15	37	
261	2.12		94.88	95.80		48	31	25	15	37	
270	2.27		94.40	93.40		49	31	25	15	35	
284	2.50		95.00	93.90		53	45	12	17	22	
289	2.58		94.90	94.50		44	45	35	17	28	

03-Dec-90

Oct 4 1990

T0= Minutes	14:25 Time		%O2 FM6	%O2 FM2	%O2 FM1	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1
310	2.93		95.00	94.60		44	45	27	11	42	
318	3.07		95.10	94.50		34	50	28	12	42	
325	3.18		94.90	94.20		30	50	32	11	39	
334	3.33		94.50	94.80		29	50	35	10	38	
348	3.57		94.10	94.10		29	50	37	10	37	
362	3.80		94.40	93.20		26	50	37	9	38	
374	4.00		94.30	93.40		26	50	39	8	35	
389	4.25	Open JT 1/100	94.00	93.00		25	52	40	8	34	
394	4.33		94.30	94.00		28	50	28	11	11	
404	4.50		95.40	93.70		31	48	35	18	30	
413	4.65		93.00	93.70		37	47	35	18	52	
421	4.78		93.70	93.90		32	50	35	12	52	
428	4.90		93.70	93.30		31	50	35	13	50	
439	5.08		94.00	93.00	95.70	25	50	35	13	40	8
450	5.27		95.00	94.00	95.10	35	47	30	15	30	8
458	5.40		94.00	94.00	95.70	40	45	35	15	30	10
464	5.50		94.00	94.00	95.90	40	45	35	15	30	11
469	5.58	Bag 2	94.00	94.00	$\boxed{96.10}$	38	46	35	15	35	11
474	5.67		94.00	94.00	96.30	39	45	35	15	35	12
479	5.75		94.00	93.50	96.50	38	47	35	15	35	12
484	5.83		94.00	93.00	97.10	32	45	35	15	35	12
489	5.92		94.00	93.00	97.20	35	48	35	15	35	12
494	6.00		94.00	93.00	97.30	30	49	30	15	35	12
499	6.08				98.00						12
506	6.20	Bag #3 Dewar #1 86									12
511	6.28				98.00						12
514	6.33				98.20						11
518	6.40				99.00						8
520	6.43				99.00						20
524	6.50	Bag # 4 ~~75~~ cross flow			97.00						8
534	6.67				96.90						10
539	6.75	Bag#5 ~~26~~ NO FLOW			97.20						13
550	6.93				98.80						13
550	6.94				98.00						13

03-Dec-90

Oct 4 1990

T0= Minutes	Psig RA-FM1		Temperatures 2	3	4	6	8	9	P5	P4	L1	L2	Gr/min Liq liter= Delta P FM-6= Derym No.	Vaporized Li FM4 SCFM
													0.0	0.0
													0.0	0.0
													0.0	0.0
2		284.7	290.8	284.0			284.1	278.6					91.7	11.5
16		274.0	280.8	284.0	281.3		280.8	269.1					93.6	11.1
19		274.7	280.2	284.0	281.3		280.0	270.0					93.6	11.1
23		273.0	280.0	284.0	280.0		280.0	270.0					90.1	10.9
26		268.6	278.0	284.0	279.7		280.2	273.6					93.6	19.9
34		271.9	278.0	284.0	279.7		283.0	282.0					93.6	19.3
36		274.7	277.4	284.0	279.1		283.0	280.2					90.1	18.9
39		274.1	277.0	284.0	279.0		280.0	255.2					83.3	18.2
42		271.3	276.3	284.0	277.4		279.7	254.7					93.6	19.3
46		266.9	274.7	284.0	276.3		277.4	268.6					93.6	19.3
52		268.6	273.6	284.0	274.1		277.0	268.6					90.1	18.9
64		271.3	273.0	284.0	273.0		273.0	273.0					93.6	19.3
69		273.0	273.0	284.0	273.0		273.0	255.2					93.6	19.3
74		273.0	273.0	284.0	273.0		273.0	241.9					86.7	18.6
79		273.0	272.0	284.0	273.0		253.0	231.0					90.1	18.9
84		271.3	264.7	284.0	250.8		250.8	223.0					90.1	18.9
89		266.9	257.4	280.0	243.0		243.0	214.7	P3	P5			90.1	18.9
94		262.0	254.0	278.0	239.0		235.9	207.0	13.0	19.0			90.1	18.9
99		257.5	247.0	277.0	225.0		224.0	196.0	13.0	19.0			90.1	18.9
104		250.0	234.0	276.0	219.0		217.0	189.0	11.0	18.0			90.1	18.9
109		245.0	234.0	275.0	219.0		217.7	189.2	11.0	18.0			90.1	18.9
114		240.0	229.0	274.0	214.0		213.0	184.6	12.0	20.0			90.1	18.9
119		235.5	223.6	273.0	208.0		206.9	179.3	14.0	20.0			90.1	18.9
129		224.0	216.0	272.0	199.0		196.0	165.9	9.0	25.0			64.5	16.0
134		220.0	208.0	270.0	192.0		189.0	161.0	9.0	25.0			60.5	16.0
144		210.0	197.0	269.0	182.0		181.0	154.0	9.0	25.0			60.5	16.0
154		204.0	191.0	268.0	176.0		173.0	147.0	9.0	24.0			68.3	16.7
164		194.0	179.0	267.0	166.9		163.0	139.0	9.0	24.0			68.3	16.7
174		184.0	169.0	266.0	157.0		154.0	131.0	8.0	22.0			63.3	16.7
179		180.0	167.0	265.0	154.2		151.7	127.0	15.0	26.0			69.0	17.5
184		176.0	161.7	264.0	148.9		146.0	124.7	14.0	26.0			73.6	17.3
204		160.0	146.0	263.0	135.5		132.6	111.0	12.0	24.0			73.6	17.3
214		154.0	140.0	263.0	129.0		127.0	103.7	12.0	22.0			76.8	17.9
224		147.0	134.0	262.0	124.0		122.0	99.0	10.0	20.0			72.0	17.9
242		134.0	121.0	260.0	112.0		110.0	89.8	10.0	18.0	0.5		67.5	16.4
248		132.0	119.0		109.0		107.0	86.7	17.0	24.0	0.6		70.5	16.7
254		131.0	117.9	259.0	108.0		106.0	88.0	15.0	23.0	0.6		74.3	17.5
261		131.0	117.0	257.0	108.0		106.0	88.0	15.0	23.0	0.8		74.3	17.9
270		127.6	113.6	254.0	106.0		104.0	86.0	13.0	22.0	0.6		77.5	17.8
284		122.0	110.0	253.0	98.5		95.9	86.9	15.0	35.0	0.6		62.4	19.3
289		121.0	108.0	251.0	97.6		94.4	86.4	15.0	35.0			43.0	16.2

03-Dec-90

Oct 4 1990

T0= Minutes	Psig RA-FM1		Temperatures 2	3	4	6	8	9	P5	P4	L1	L2	Gr/min Liq liter= Delta P FM-6- Derym No.	Vaporized Li FM4 SCFM
310		121.0	108.0	248.0	96.5		94.0	86.7	22.0	37.0	0.8		43.0	16.2
318		122.0	109.0	245.0	92.0		95.0	86.7	8.0	40.0	0.8		23.1	12.5
325		123.0	111.0	244.6	89.5		95.4	87.3	18.0	45.0	0.8		18.0	12.6
334		124.0	112.0	242.0	88.0		95.3	87.0	7.0	44.0	4.0		16.8	12.2
348		126.0	113.0	240.0	88.5		95.0	86.7	12.0	48.0	4.0		16.8	12.2
362		126.0	113.0	238.8	88.4		95.4	86.8	9.0	50.0	4.3		13.5	11.4
374		126.7	113.0	237.0	87.3		95.7	87.4	5.0	45.0	4.0		13.5	11.4
389		127.0	113.0	235.0	86.8		94.8	86.8	4.0	40.0	5.0		12.0	11.0
394		126.7	113.7	234.0	89.2		95.5	87.6	19.0	46.0	4.6		15.7	12.3
404		124.7	112.0	233.6	90.7		94.0	86.6	10.0	35.0	5.8	0.8	20.0	13.6
413		123.8	111.6	232.0	91.5		94.0	86.6	25.0	40.0	5.0	0.8	29.1	16.2
421		123.5	110.9	232.0	91.3		95.4	86.0	15.0	43.0	4.9	0.8	20.5	14.2
428		123.7	111.0	231.6	89.7		94.0	86.0	14.0	40.0	5.3	0.8	19.2	13.6
439	30	124.5	112.0	231.0	88.6		95.2	86.8	10.0	40.0	5.5	1.5	12.5	10.8
450	25	124.8	112.0	231.0	91.0		95.6	85.5	9.0	30.0	5.0	2.0	26.1	15.0
458	20	123.1	111.0	231.0	93.0		93.9	86.5	40.0	24.0	5.0	3.5	35.6	17.5
464	20	122.0	110.0	231.0	94.0		93.1	85.0	13.0	33.0	5.0	3.8	35.6	17.5
469	20	122.0	110.5	232.0	93.5		93.8	85.9	26.0	40.0	5.0	4.0	31.4	16.6
474	20	122.5	110.0	232.0	93.7		93.3	85.8	12.0	35.0	4.5	4.0	33.8	16.7
479	20	122.7	111.0	233.7	93.1		94.1	87.4	23.0	40.0	4.5	4.0	30.7	16.0
484	20	123.7	111.0	236.0	91.8		94.1	86.5	9.0	40.0	4.3	4.5	22.8	13.5
489	20	123.8	111.9	238.4	91.2		95.4	87.4	20.0	44.0	4.3	4.5	25.5	14.8
494	20	124.5	112.5	241.0	90.4		95.2	87.0	10.0	40.0	4.3	4.5	18.4	12.6
499	20										4.0	4.5	0.0	0.0
506	20												0.0	0.0
511	20										3.5	4.0	0.0	0.0
514	18										3.5	4.0	0.0	0.0
518	15										2.5	4.0	0.0	0.0
520	11										1.5	4.0	0.0	0.0
524	15										0.0	3.5	0.0	0.0
534	15										0.0	3.0	0.0	0.0
539	15										0.0	2.8	0.0	0.0
550	15										0.0	2.0	0.0	0.0
550	15										0.0	0.0	0.0	0.0

03-Dec-90

Oct 4 1990	Coeff=		186.9	AR	NTP #/ft3 0.1034	Coeff 4.4521	GR/min 208.8	GR/liq 1 1393	1290
	3.50		1142	O2	0.0828	4.9749	186.9	1142	
	uid to cool dewar=			Air	0.0749	14.6000	496.2		
					1.00				
T0= Minutes	-FM1 Gr/min	FM2 Gr/min	FM6 Gr/min	Liters Dewar1	Liters Dewar2	Liters L1	Liters L2	Liters Liq withdrawn	L STP withdrw
	0.0		0.0						
	0.0		0.0						
	0.0		0.0						
2	0.0		0.0						
16	0.0		0.0						
19	0.0		0.0						
23	0.0		0.0						
26	0.0		0.0						
34	0.0		0.0						
36	0.0		0.0						
39	0.0		0.0			0.0			
42	0.0		0.0			0.0			
46	0.0		0.0			0.0			
52	0.0		0.0			0.0			
64	0.0		0.0			0.0	0.0		
69	0.0		0.0			0.0	0.0		
74	0.0		0.0			0.0	0.0		
79	0.0		0.0			0.0	0.0		
84	0.0		0.0			0.0	0.0		
89	0.0		0.0			0.0	0.0		
94	0.0		0.0			0.0	0.0		
99	0.0		0.0			0.0	0.0		
104	0.0		0.0			0.0	0.0		
109	0.0		0.0			0.0	0.0		
114	0.0		0.0			0.0	0.0		
119	0.0		0.0			0.0	0.0		
129	0.0		0.0			0.0	0.0	0.0	0
134	0.0		0.0			0.0	0.0	0.0	0
144	0.0		0.0			0.0	0.0	0.0	0
154	0.0		0.0			0.0	0.0	0.0	0
164	0.0		0.0			0.0	0.0	0.0	0
174	0.0		0.0			0.0	0.0	0.0	0
179	0.0		0.0			0.0	0.0	0.0	0
184	0.0		0.0			0.0	0.0	0.0	0
204	0.0		0.0			0.0	0.0	0.0	0
214	0.0		0.0			0.0	0.0	0.0	0
224	0.0		0.0	0.0		0.0	0.0	0.0	0
242	0.0	71.0	70.2	-0.0		0.2	0.0	0.0	0
248	0.0	71.0	70.2	-0.0		0.3	0.0	0.0	0
254	0.0	69.2	70.2	-0.0		0.3	0.0	0.0	0
261	0.0	69.2	70.2	-0.0		0.3	0.0	0.0	0
270	0.0	65.4	70.2	0.0		0.3	0.0	0.0	0.0
284	0.0	41.1	34.7	0.0		0.3	0.0	0.0	0.0
289	0.0	52.3	101.2	0.1		0.0	0.0	0.0	0.0

03-Dec-90

Oct 4 1990	Coeff=		186.9	AR	NTP #/ft3 0.1034	Coeff 4.4521	GR/min 208.8	GR/liq l 1393	1290
			1142	O2	0.0828	4.9749	186.9	1142	
	3.50			Air	0.0749	14.6000	496.2		
	uid to cool dewar=				1.00				
T0= Minutes	-FM1 Gr/min	FM2 Gr/min	FM6 Gr/min	Liters Dewar1	Liters Dewar2	Liters L1	Liters L2	Liters Liq withdrawn	L STP withdr v
310	0.0	78.5	71.1	0.5		0.3	0.0	0.0	0.0
318	0.0	78.5	75.0	0.4		0.3	0.0	0.0	0.0
325	0.0	72.9	84.3	0.5		0.3	0.0	0.0	0.0
334	0.0	71.0	90.6	0.6		1.7	0.0	0.0	0.0
348	0.0	69.2	95.8	0.9		1.7	0.0	0.0	0.0
362	0.0	71.0	94.1	1.2		1.8	0.0	0.0	0.0
374	0.0	65.4	97.3	1.5		1.7	0.0	0.0	0.0
389	0.0	63.5	99.8	1.9		2.1	0.0	0.0	0.0
394	0.0	20.6	73.8	2.1		1.9	0.0	0.0	0.0
404	0.0	56.1	102.7	2.1	0.1	2.4	0.3	0.0	0.0
413	0.0	97.2	102.7	2.1	0.1	2.1	0.3	0.0	0.0
421	0.0	97.2	93.8	2.1	0.2	2.1	0.3	0.0	0.0
428	0.0	93.5	95.3	2.1	0.1	2.2	0.3	0.0	0.0
439	-26.1	74.8	95.3	2.0	0.2	2.3	0.6	0.1	10.5
450	-24.6	56.1	84.3	1.7	0.4	2.1	0.8	0.4	10.5
458	-28.7	56.1	98.3	1.6	0.7	2.1	1.5	0.6	13.1
464	-31.6	56.1	98.3	1.4	0.9	2.1	1.6	0.7	14.4
469	-31.6	65.4	98.3	1.3	1.1	2.1	1.7	0.9	14.4
474	-34.5	65.4	98.3	1.1	1.2	1.9	1.7	1.0	15.7
479	-34.5	65.4	98.3	1.0	1.4	1.9	1.7	1.1	15.7
484	-34.5	65.4	98.3	0.8	1.5	1.8	1.9	1.3	15.7
489	-34.5	65.4	98.3	0.7	1.7	1.8	1.9	1.5	15.7
494	-34.5	65.4	84.3	0.5	1.8	1.8	1.9	1.6	15.7
499	-34.5	0.0	0.0	0.4	1.7	1.7	1.9	1.8	15.7
506	-34.5	0.0	0.0	0.1	1.4	1.6	0.0	2.0	15.7
511	-34.5	0.0	0.0	0.0	1.3	1.5	1.7	2.1	15.7
514	-30.7	0.0	0.0	0.0	1.2	1.5	1.7	2.2	14.4
518	-21.3	0.0	0.0	0.0	1.1	1.0	1.7	2.3	10.5
[illegible]	-49.4	0.0	0.0	0.0	1.1	0.6	1.7	2.4	26.2
[illegible]	-21.3	0.0	0.0	0.0	0.9	0.0	1.5	2.5	10.5
[illegible]	-26.6	0.0	0.0	0.0	0.7	0.0	1.3	2.7	13.1
[illegible]	-34.5	0.0	0.0	0.0	0.6	0.0	1.2	2.8	17.0
550	-34.5	0.0	0.0	0.0	0.3	0.0	0.8	3.2	17.0
550	-34.5	0.0	0.0	0.0	0.2	0.0	0.0	3.2	17.0

03-Dec-90

	TOn Minutes	Liters Liq withdrawn	L STP withdrw
[illegible]			
	317.0	1.2	
	323.1	1.2	
	338.4	1.2	
	339.9	1.2	
	348.2	1.2	
	353.4	1.2	
	362.3	1.2	
	373.5	1.2	
	383.8	1.2	
	393.3	1.2	
	398.4	1.2	
	403.8	1.3	13.1
	411.9	1.5	13.1
	424.5	1.7	
	425.9	1.7	13.1
	429.4	1.8	
	435.4	1.8	10.5
	442.5	1.9	13.1
	444.5	1.9	19.6
	445.0	2.0	43.2
	446.4	2.1	52.3
	448.4	2.2	45.8
	449.3	2.3	65.4
	451.9	2.6	62.8
	452.7	2.7	43.2
	454.7	2.8	37.9
	455.0	2.8	34.0
	456.2	2.9	28.8
	457.1	2.9	18.3
	460.5		

@now~

@now~
{/ Block;Values}~
~

T0= Minutes	Liters Liq withdrawn	L STP withdrw
3.4		
7.1		
11.6		
15.2		
26.6		
29.0		
32.2		
36.7		
39.7		
42.1		
44.8		
48.6		
50.2		
53.4		
56.5		
64.1		
70.6		
83.5		
100.6		
115.0		
125.0		
135.0		
136.7		
141.7		
145.6		
154.0		
160.4		
166.7		
171.3		
176.5		
182.1		
186.5		
190.6		
196.1		
198.8		
204.3		
222.6		
227.1		
232.9		
236.1		
241.6		
246.2		
252.6		
257.4		
262.5		
270.3		
275.4		
279.6	0.1	15.7
289.1	0.3	15.7
298.7	0.9	49.7
306.2	1.2	
312.0	1.2	

03-Dec-90

@now~

T0= Minutes	Temperatures 3	4	6	8	9	P3	P7	L1	L2	Deryn No.	Vaporized Liquid to cool dewars FM4 SCFM	-FM1 Gr/min	FM2 Gr/min	FM6 Gr/min	Liters Dewar1	1.00 Liters Dewar2	Liters L1	Liters L2
317.0	255.8	97.1		97.7	86.5	33.0	14.0	0.9		44.1	20.1		65.4	99.8	0.4		0.4	
323.1	255.5	96.3		96.8	86.5	30.0	12.0	0.9		40.5	19.7		65.4	98.3	0.6		0.4	
338.4	254.5	94.8		92.8	85.7	30.0	11.0	1.0		32.0	17.1		65.4	98.3	1.1		0.4	
339.9	253.6	94.8		94.2	87.7	35.0	18.0	1.0		48.0	20.5		65.4	98.3	1.1		0.4	
348.2	252.1	95.7		95.8	85.7	25.0	10.0	1.0		38.7	19.0		65.4	98.3	1.4		0.4	
353.4	251.1	94.9		94.0	87.0	35.0	17.0	4.0		48.0	21.0		65.4	98.3	1.5		1.7	
362.3	248.3	93.9		94.3	87.3	40.0	15.0	4.0		48.0	21.0		65.4	96.8	1.8		1.7	
373.5	246.2	93.4		94.3	87.4	35.0	10.0	4.5		38.5	18.5		65.4	99.1	2.1		1.9	
383.8	244.0	92.3		94.6	87.6	40.0	18.0	4.8		40.5	19.7		65.4	107.2	2.1		2.0	
393.3	241.0	92.1		94.6	87.5	38.0	10.0	4.8	0.5	35.3	18.1		89.7	98.3	2.1	0.2	2.0	0.2
398.4	240.4	92.3		95.3	87.9	43.0	13.0	4.8	0.9	35.3	18.1		93.5	112.1	2.1	0.3	2.0	0.4
403.8	238.8	92.0		95.2	88.1	40.0	12.0	4.2	1.0	35.3	18.1	-28.7	87.8	117.3	2.0	0.3	1.8	0.4
411.9	237.9	92.1		95.4	91.1	40.0	10.0	3.5	1.0	26.3	16.6	-31.5	65.4	118.5	1.9	0.5	1.5	0.4
424.5	237.1	92.1		96.3	88.9	48.0	12.0	4.0	2.5	18.8	14.5		69.2	108.2	1.8	1.0	1.6	1.0
425.9	236.0	91.7		96.3	88.8	50.0	10.0	3.5	4.0	26.3	16.6	-29.9	65.4	98.3	1.[illegible]	1.0	1.5	1.7
429.4								4.5	4.1	18.2	14.5		65.4	101.1	1.8	1.1	1.9	1.7
435.4	235.0	94.3		96.2	87.8	48.0	15.0	4.0	4.5	43.7	22.3	-15.0	76.6	98.3	1.8	1.2	1.7	1.9
442.5								3.5	3.5			-18.7			1.7	1.2	1.5	1.5
444.5								3.5	3.5			-28.0			1.7	1.2	1.5	1.5
445.0								3.3	3.3			-116.8			1.7	1.2	1.4	1.4
446.4								3.0	3.0			-74.8			1.6	1.1	1.3	1.3
448.4								2.9	2.8			-65.4			1.6	1.1	1.2	1.2
449.3								2.9	2.9			-143.6			1.5	1.0	1.2	1.2
451.9								2.5	2.5			-127.5			1.4	0.9	1.0	1.0
452.7								2.4	2.4			-71.4			1.4	0.8	1.0	1.0
454.7								2.5	2.0			-62.7			1.3	0.8	1.0	0.8
455.0								1.9				-51.8			1.3	0.8	0.8	
456.2												-41.1			1.3	0.7		
457.1												-26.2			1.2	0.7		
460.5																		

03-Dec-90

@now~

@now~
(/ Block;Values)~
~

T0= Minutes	Temperatures 3	4	6	8	9	P3	P7	L1	L2	Derym No.	Vaporized Liquid to cool dewars FM4 SCFM	-FM1 Gr/min	FM2 Gr/min	FM6 Gr/min	Liters Dewar1	1.00 Liters Dewar2	Liters L1	Liters L2
3.4	283.0	284.5		285.1	268.0	17.0	22.0			94.5	11.5							
7.1	284.3	283.0		281.5	263.0	18.0	23.0			88.4	11.3							
11.6	283.0	281.8		282.0	272.5	18.0	24.0			91.1	11.3							
15.2	282.0	280.0		280.0	265.0	18.0	23.0			91.1	11.3							
26.6	281.1	282.2		276.2	273.8	18.0	23.0			97.6	20.5							
29.0	284.4	277.0		275.9	272.5	18.0	23.0			97.6	20.7							
32.2	232.0	274.5		275.5	256.0	18.0	23.0			94.5	20.5							
36.7	284.0	275.3		275.2	269.8					94.5	20.5							
39.7	285.0	274.7		274.7	258.6					97.6	20.2							
42.1	285.0	274.0		274.2	255.7					94.1	19.9							
44.8	285.0	275.0		274.0	271.0					101.2	20.8							
48.6	285.0	274.0		278.2	279.5					97.6	20.5							
50.2	285.0	273.0		277.0	280.0					97.6	20.2							
53.4	285.0	273.4		276.3	257.0					94.5	20.2							
56.5	285.0	272.2		273.6	265.2					91.7	20.2							
64.1	283.4	270.0		267.8	245.5	31.0	13.0			94.1	19.9							
70.6	283.0	260.1		256.2	230.0	30.0	12.0			62.4	19.5							
83.5	282.3	241.1		237.7	212.8					62.4	19.7							
100.6	280.8	219.3		216.2	193.0	28.0	12.0			58.8	19.6							
115.0	280.0	208.5		205.8	186.7	27.0	12.0			54.2	18.8							
125.0	278.0	207.7		204.8	183.4	32.0	20.0			56.3	21.9							
135.0	277.7	200.6		197.8	174.8	35.0	15.0			46.1	20.2							
136.7	276.6	191.9		189.0	165.3	38.0	14.0			53.2	21.2							
141.7	275.9	187.1		184.1	160.4	37.0	13.0			40.5	19.4							
145.6	275.3	183.4		180.1	157.1	37.0	13.0			43.2	19.8							
154.0	273.9	174.3		171.0	147.7	37.0	14.0			46.1	21.0							
160.4	273.0	168.7		166.2	144.7	35.0	13.0			46.0	20.1							
166.7	271.9	163.5		161.2	140.5	35.0	13.0			50.0	21.9							
171.3	271.3	159.1		156.8	136.5	35.0	13.0			50.0	21.3							
176.5	270.7	156.3		154.1	134.3	35.0	13.0			49.0	21.0							
182.1	269.9	152.0		149.8	131.2	33.0	13.0			50.0	21.6							
186.5	269.4	149.2		147.0	127.6	33.0	13.0			48.0	21.0							
190.6	268.8	146.6		144.1	124.7	33.0	13.0			48.0	20.7			28.1				
196.1	267.4	139.7		137.2	119.0	36.0	10.0			44.1	19.8			22.5				
198.8	267.4	139.7		137.2	119.0	36.0	20.0			50.0	21.5		18.7	22.5				
204.3	266.6	134.7		132.9	115.0	34.0	15.0			53.2	21.6		18.7	22.5				
222.6	263.5	127.5		126.0	108.0	30.0	12.0			51.0	21.6		18.7	22.5				
227.1	262.0	125.5		124.8	102.9	35.0	20.0			57.3	22.9		18.7	22.5				
232.9	260.0	122.4		121.3	103.0	33.0	19.0			58.5	22.9							
236.1	260.5	120.5		119.7	101.5	33.0	18.0			60.8	23.1							
241.6	259.8	117.8		116.9	98.8	34.0	19.0			61.1	23.0							
246.2	259.1	115.5		114.7	96.9	32.0	18.0			67.7	24.8							
252.6	257.9	111.9		110.9	93.4	32.0	18.0			65.3	24.1							
257.4	257.2	109.7		108.7	92.0	32.0	[illegible]			64.4	23.7							
262.5	256.2	106.8		105.8	89.3	32.0	18.0			63.0	23.3							
270.3	254.7	102.7	101.4	101.4	89.2	30.0	18.0			63.0	23.7		41.1	73.5				
275.4	253.8	100.3		99.2	86.7	30.0	17.0			63.0	23.7		39.2	99.8	0.1			
279.6	253.5	98.2		96.6	87.6	40.0	14.0			46.1	20.5	-32.9	44.9	86.8	0.1			
289.1	254.1	97.6		97.3	87.6	34.0	12.0			40.5	19.4	-32.9	46.7	57.8	0.1			
298.7	255.2	97.7		98.2	87.6	31.0	11.0			58.3	23.3	-102.6	65.4	156.8	0.1			
306.2	256.0	98.4		99.0	88.3	35.0	15.0			57.5	22.4		65.4	99.8	0.1			
312.0	256.0	98.1		98.8	87.2	35.0	15.0	0.6		49.0	21.0		65.4	99.8	0.3		0.3	

03-Dec-90

@now~

T0= Minutes	14:25 Time		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1	Psig RA-FM1	1	2
317.0	05:31:48 PM		96.38	96.19		46	48	35	16	35			117.4	106.3
323.1	05:37:56 PM		96.76	96.40		45	50	35	15	35			117.0	106.4
338.4	05:53:15 PM	sv2-7 up	96.59	96.61		40	50	35	15	35			117.1	106.8
339.9	05:54:43 PM	sv1-8 down	95.69	96.12		48	48	35	15	35			117.3	110.1
348.2	06:03:00 PM		96.70	96.32		44	50	35	15	35			117.6	106.4
353.4	06:08:15 PM	sv2-7 up	96.57	93.74		48	48	35	15	35			117.5	106.7
362.3	06:17:05 PM	sv1-8 down	95.17	94.65		48	48	35	14	35			116.7	106.7
373.5	06:28:19 PM	sv2-7 up	92.64	92.11		43	48	37	12	35			117.6	107.0
383.8	06:38:39 PM	HV-60	95.60	94.20		45	50	40	12	35			117.9	107.3
393.3	06:48:05 PM		90.90	94.00		42	50	35	15	48			118.0	107.4
398.4	06:53:11 PM	sv1-8 down	94.50	96.28		42	50	35	25	50			118.2	107.5
403.8	06:58:39 PM		95.95	95.37	93.65	42	50	40	18	47	10	20	118.7	107.5
411.9	07:06:45 PM		95.34	95.00	96.30	38	55	35	30	35	10	27	118.9	107.8
424.5	07:19:21 PM		96.70	96.47	96.50	33	58	35	22	37			118.8	107.7
425.9	07:20:40 PM		96.70	96.00	97.20	38	55	35	15	35	10	23	118.0	107.5
429.4	07:24:12 PM		95.00	97.50	97.50	33	60	36	15	35				
435.4	07:30:11 PM	JT open fraction	95.00	95.20	97.50	49	55	35	15	41	8		118.0	106.0
442.5	07:37:16 PM	ALL OFF			97.50						10			
444.5	07:39:17 PM				98.30						15			
445.0					98.30						33	38		
446.4	07:41:15 PM				98.50						40			
448.4	07:43:11 PM				98.20						35			
449.3	07:44:06 PM				98.70						50	20		
451.9	07:46:41 PM				98.90						48	15		
452.7	07:47:29 PM				99.00						33	5		
454.7	07:49:30 PM				99.70						29	5		
455.0	07:49:46 PM				100.00						26	2		
456.2	07:51:03 PM				100.00						22			
457.1	07:51:55 PM				100.00						14			
460.5	07:55:20 PM													

03-Dec-90

02 Test No. 6

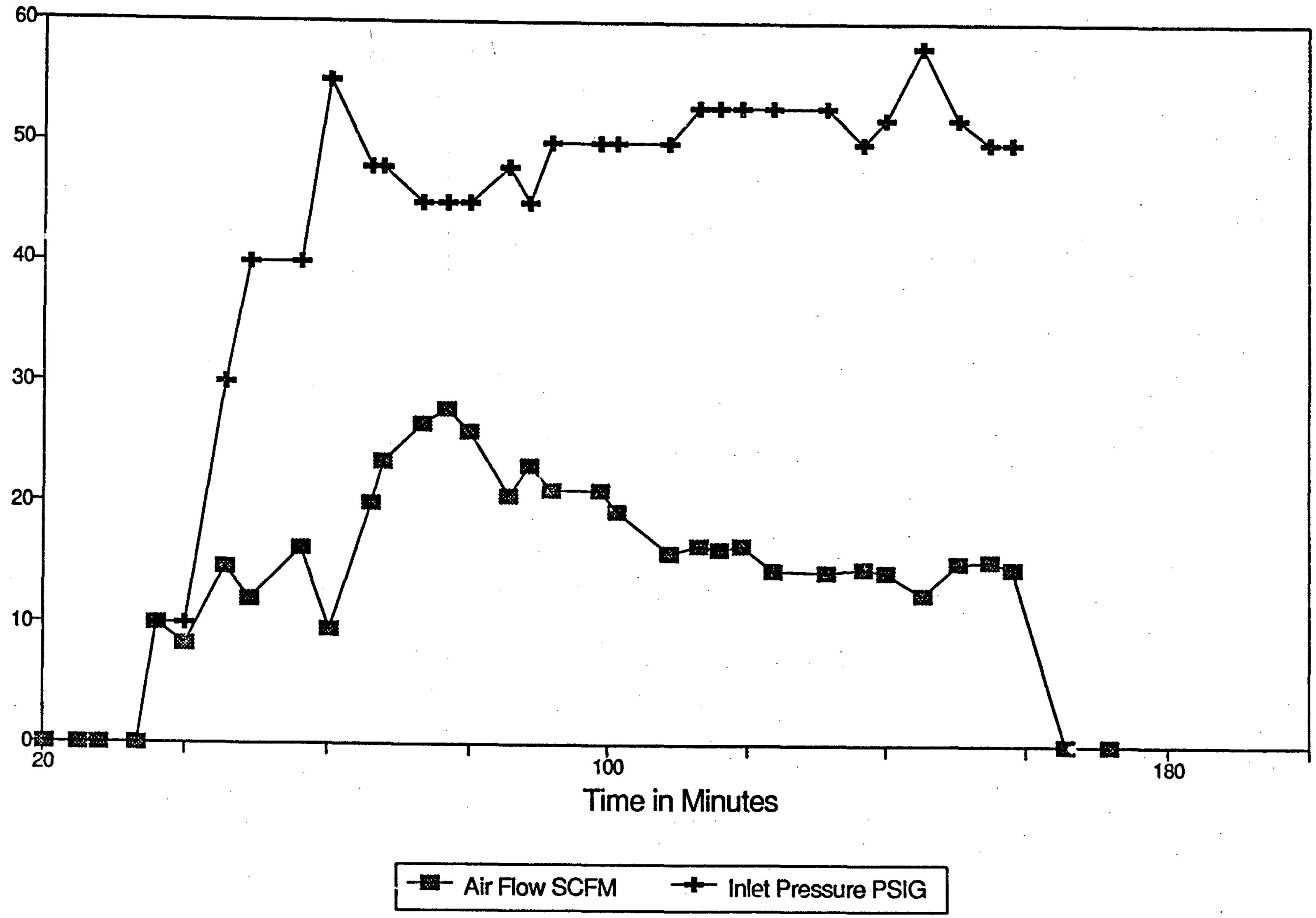
T0= Minutes	14:25 Time		%O2 FM6 supply	%O2 FM2 vent	%O2 FM1 withdraw	Q FM4	Psig Ra2	Q FM-6	Psig Ra5	Q FM2	Q FM1	Psig RA-FM1	1	2
@now~														
@now~			supply	vent	withdraw									
{/ Block;Values}~	12:14:49 PM													
~														
3.4	12:18:16 PM	coldhead on sv2-7 down				55	32						285.0	281.8
7.1	12:21:55 PM	ch off				54	33						279.0	283.0
11.6	12:26:22 PM	ch on				54	32						277.0	281.0
15.2	12:30:02 PM	ch off open hv6, close sv7				54	32						271.5	277.0
26.6	12:41:23 PM	ch off				55	31						271.9	275.5
29.0	12:43:50 PM	CH on				55	31						272.0	275.9
32.2	12:46:58 PM	off				55	32						270.0	275.3
36.7	12:51:30 PM	off				55	32						268.9	274.5
39.7	12:54:31 PM	ch on				55	31						269.3	274.7
42.1	12:56:55 PM	off				54	31						267.6	273.8
44.8	12:59:38 PM	DEFROST				56	31						267.8	273.4
48.6	01:03:22 PM	sv2-7 down ch off				55	31						270.9	273.6
50.2	01:04:59 PM	ch on				55	31						269.0	273.0
53.4	01:08:15 PM	ch off				55	32						268.8	273.4
56.5	01:11:17 PM	ch off sv1-8 down				55	33						268.4	272.4
64.1	01:18:56 PM	RUN CH ON				54	31						270.0	271.1
70.6	01:25:25 PM					53	45						269.4	268.2
83.5	01:38:16 PM	sv1-8 down				53	45						258.9	252.2
100.6	01:55:25 PM					52	46						241.9	231.1
115.0						51	48						231.0	219.8
125.0		sv2-7				52	48						229.0	218.6
135.0	02:29:49 PM	J-T close 1/10				48	50						223.0	211.7
136.7	02:31:31 PM					50	47						214.9	203.5
141.7	02:36:29 PM					45	50						210.4	199.0
145.6	02:40:22 PM	J-t close 1/10				46	49						206.8	195.2
154.0	02:48:50 PM					48	50						198.7	187.2
160.4	02:55:12 PM					47	48						193.0	180.5
166.7	03:01:32 PM					50	50						186.9	174.3
171.3	03:06:04 PM					49	48						183.1	170.4
176.5	03:11:21 PM					48	48						178.9	166.1
182.1	03:16:55 PM					50	50						174.2	161.3
186.5	03:21:19 PM					48	48						171.1	158.1
190.6	03:25:23 PM					48	48	10	15	10			168.1	155.4
196.1	03:30:52 PM					46	48	8	15	10			162.1	149.3
198.8	03:33:35 PM					49	48	8	15	10			162.1	149.3
204.3	03:39:06 PM	sv1-8				50	47	8	15	10			159.3	146.0
222.6	03:57:26 PM		96.50			50	49	8	15	10			148.9	135.8
227.1	04:01:58 PM	sv2-8 up	96.60			53	49	8	15	10			147.0	134.3
232.9	04:07:42 PM	O2 Off				53	48		15				143.0	130.3
236.1	04:10:52 PM					54	48		10				140.2	127.8
241.6	04:16:24 PM					53	46						137.7	125.3
246.2	04:21:03 PM					57	48						134.9	122.7
252.6	04:27:27 PM					56	48						130.3	118.6
257.4	04:32:10 PM					55	47						127.2	116.0
262.5	04:37:20 PM					55	48						124.0	112.9
270.3	04:45:09 PM		94.82			55	48	27	13	22			119.3	108.3
275.4	04:50:-0 PM		96.22			55	48	35	16	21			116.8	106.0
279.6	04:54:22 PM	sv-1-8 jt in 1/100	96.71	96.09		48	50	30	17	24	12	17	116.9	106.2
289.1	05:03:53 PM		95.00	96.33		45	50	20	17	25	12	17	118.7	106.7
298.7	05:13:28 PM		95.00	93.19		54	50	55	16	35	38	16	119.7	106.6
306.2	05:20:58 PM	sv2-7 up	96.25	95.58		52	47	35	16	35			119.8	106.9
312.0	05:26:49 PM		96.28	96.08		48	47	35	16	35			118.5	106.6

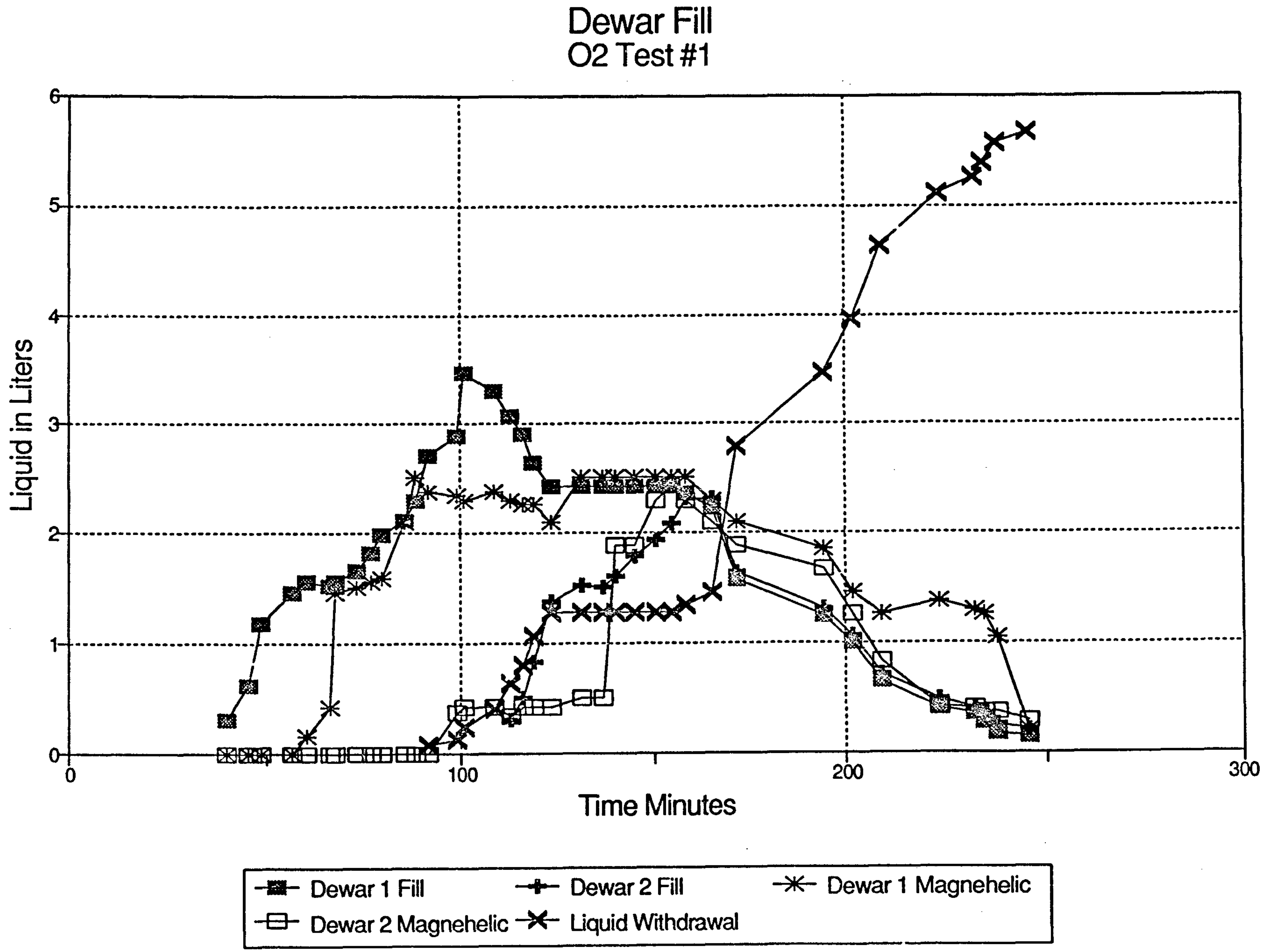
03-Dec-90

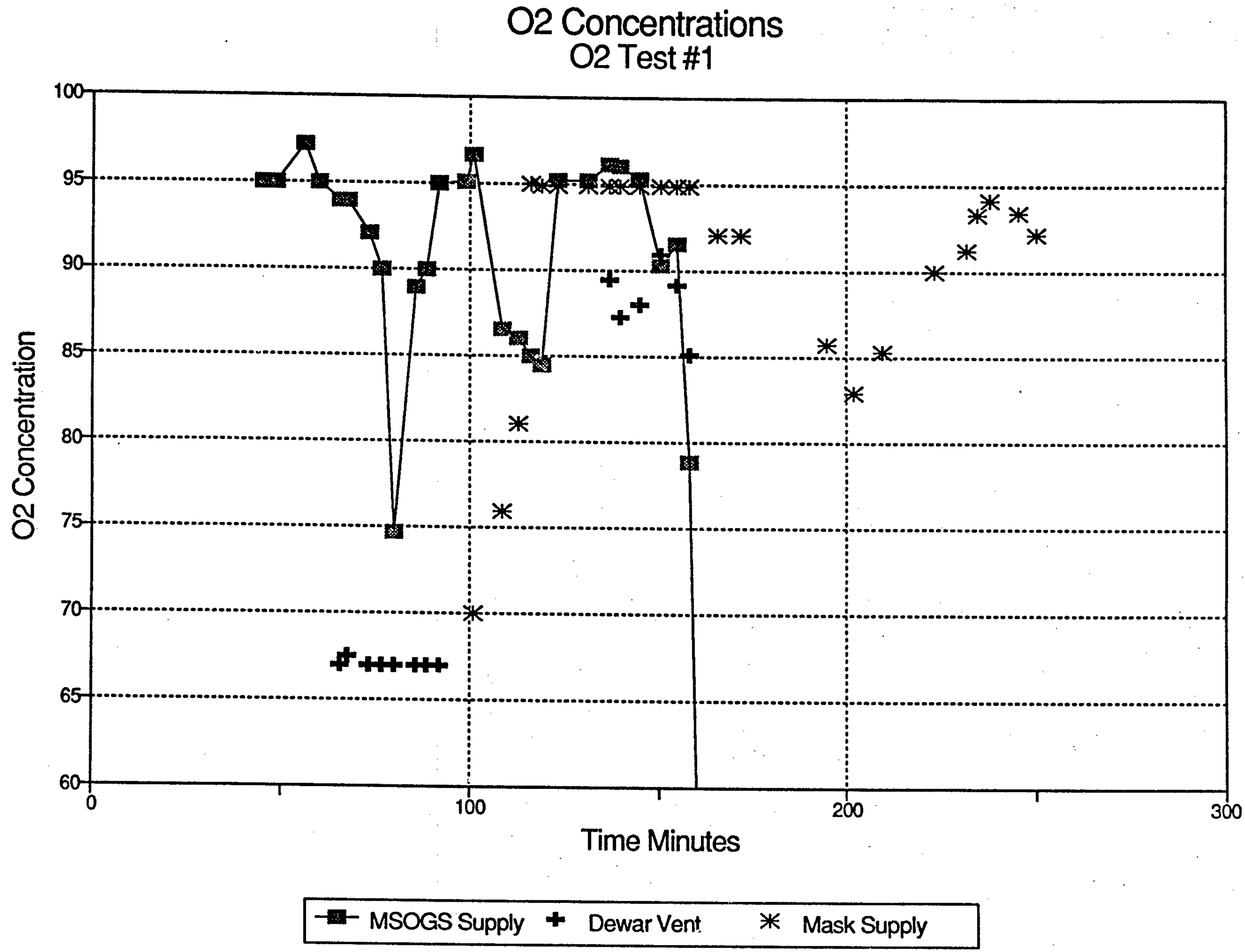
7.6.2 Test Data Graphs

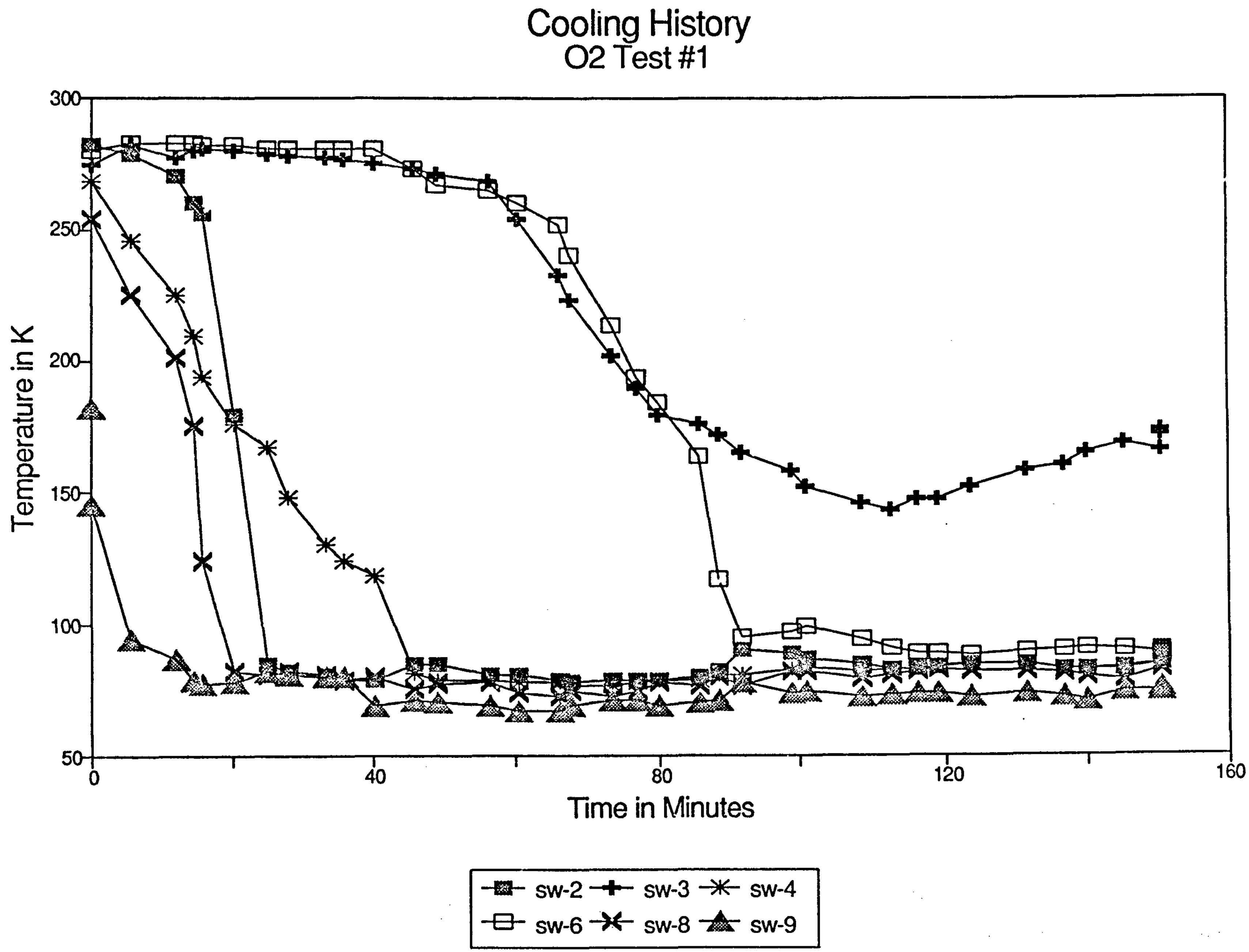
02 Test No. 1 Graphs

Heat Exchanger Deriming
O2Test #1



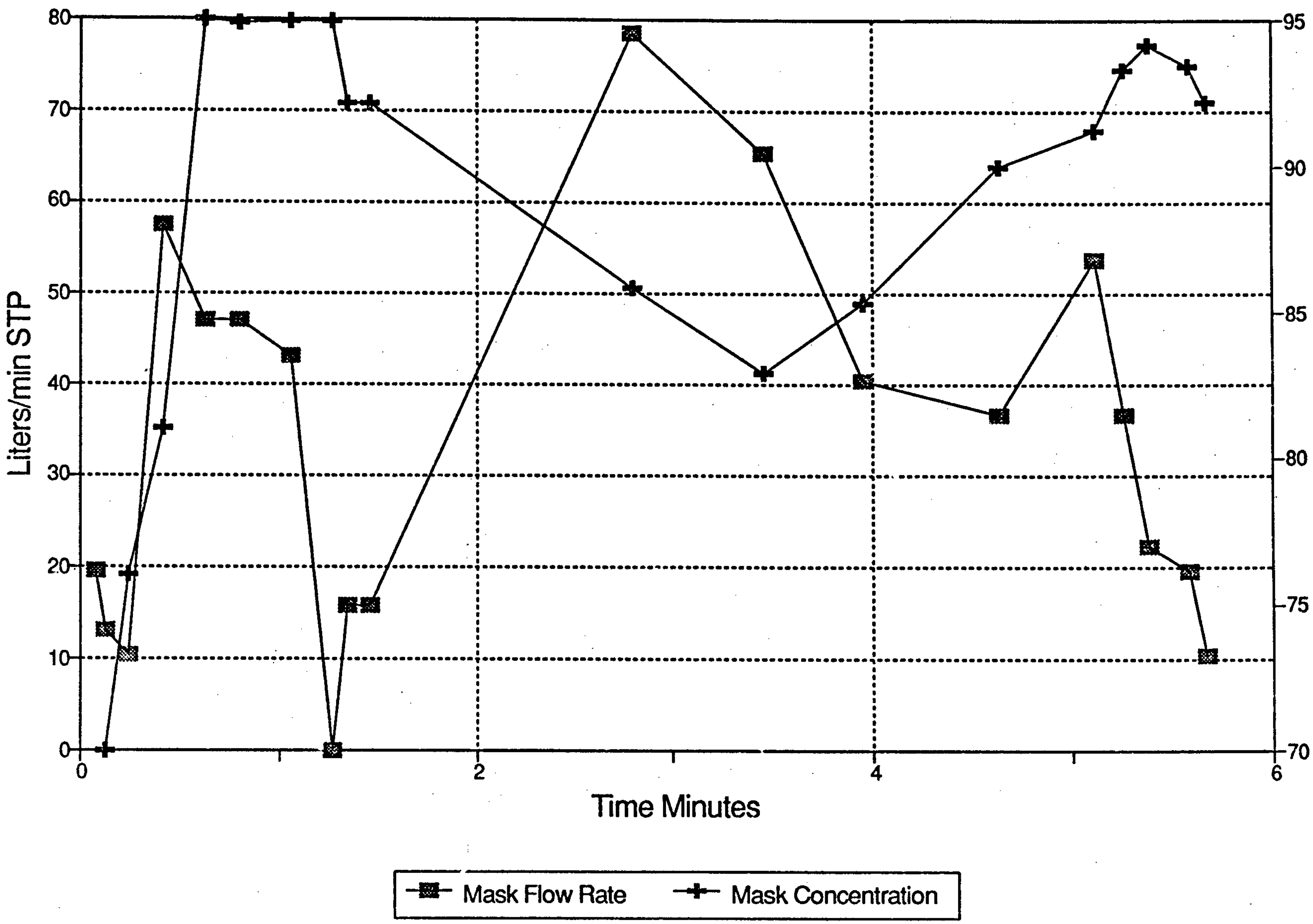

Dewar Fill
O2 Test #1
Liquid in Liters
0
1
2
3
4
5
6
0
100
200
300
Time Minutes
Dewar 1 Fill
Dewar 2 Fill
Dewar 1 Magnehelic
Dewar 2 Magnehelic
Liquid Withdrawal


O2 Concentrations
O2 Test #1
O2 Concentration
100
95
90
85
80
75
70
65
60
0
100
200
300
Time Minutes
MSOGS Supply
Dewar Vent
Mask Supply

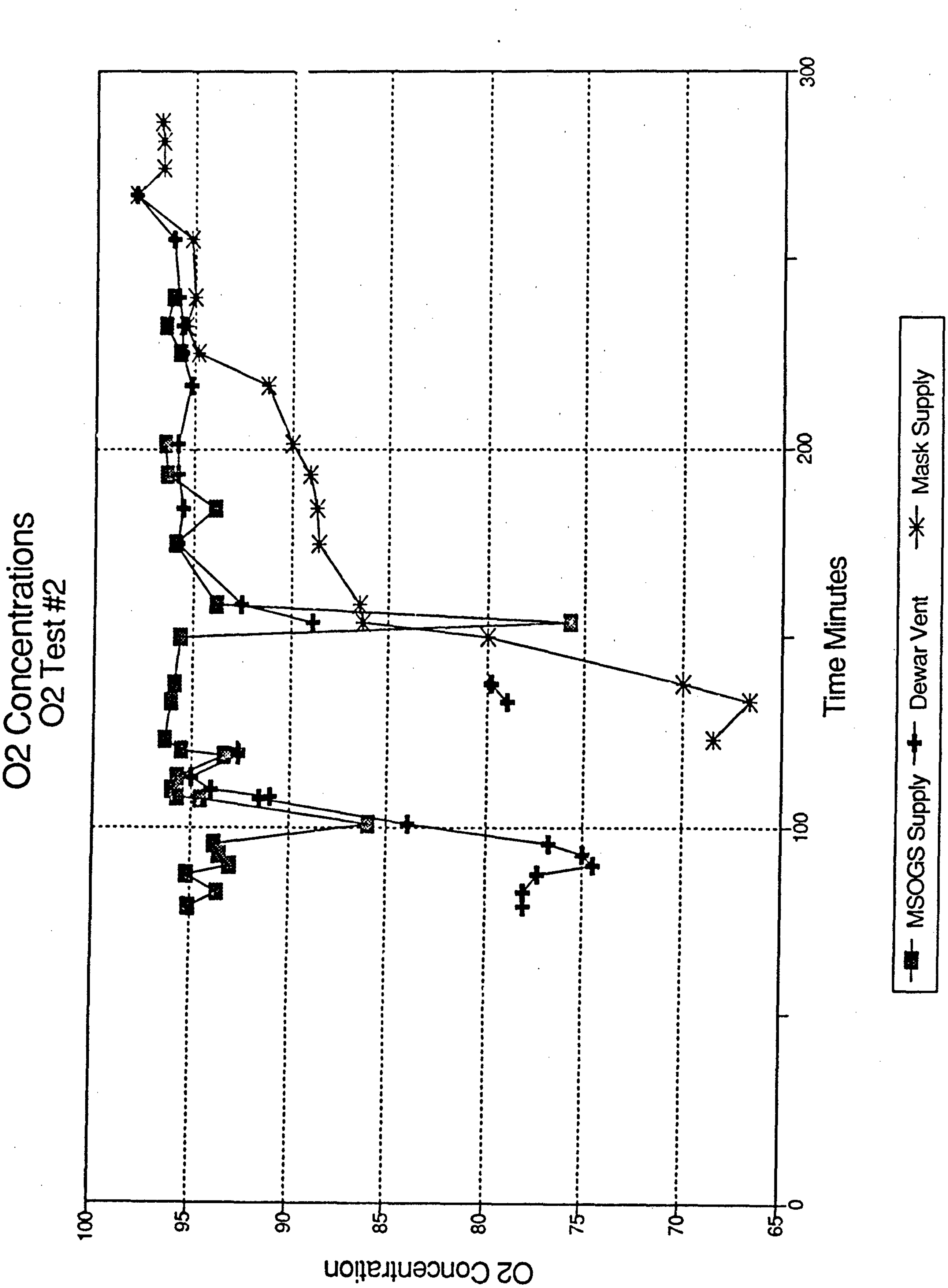


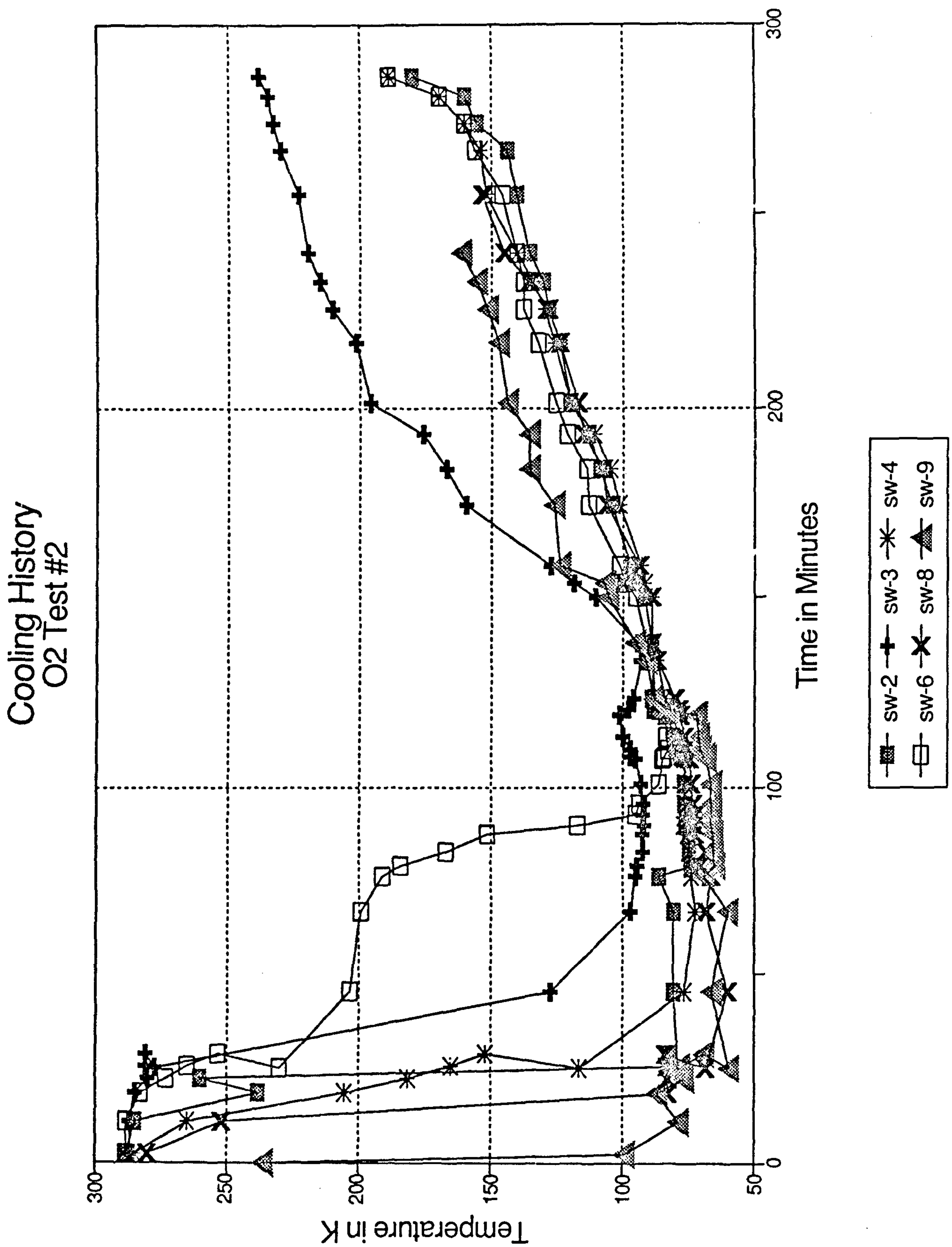
Cooling History
O2 Test #1
Temperature in K
300
250
200
150
100
50
0
40
80
120
160
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9

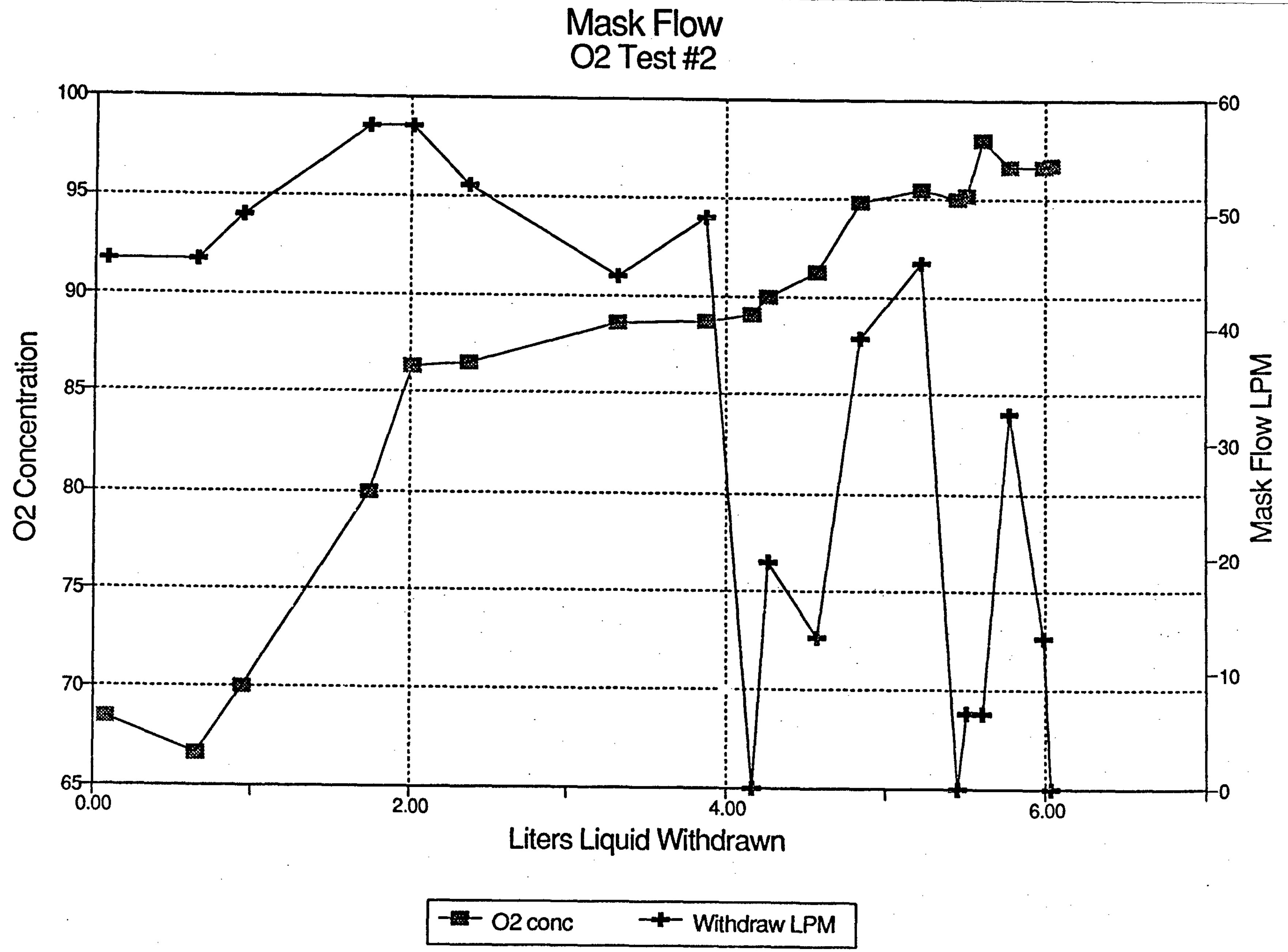
O2 Concentrations
O2 Test #1

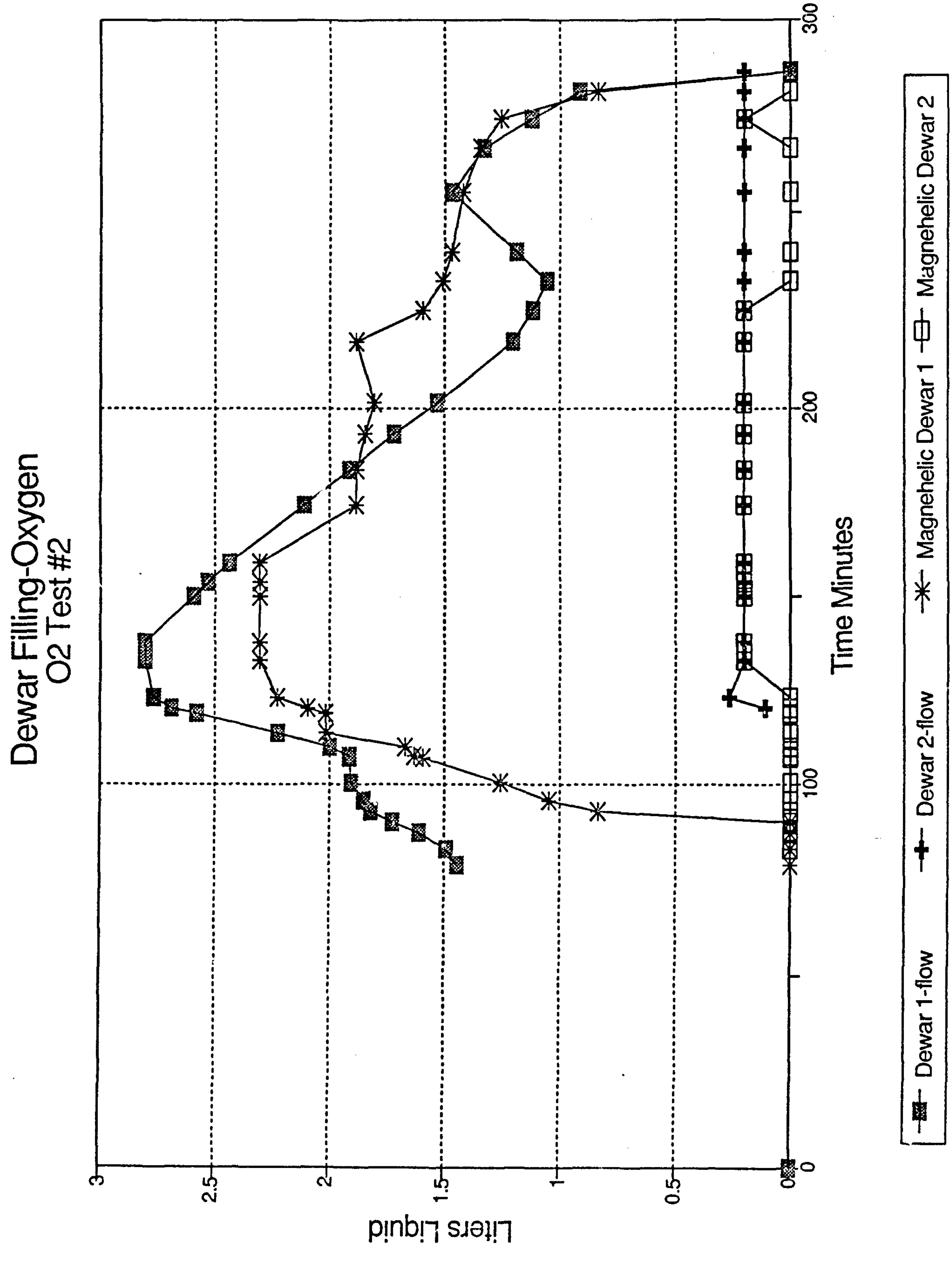


02 Test No. 2 Graphs


O2 Concentrations
O2 Test #2
O2 Concentration
100
95
90
85
80
75
70
65
0
100
200
300
Time Minutes
MSOGS Supply
Dewar Vent
Mask Supply

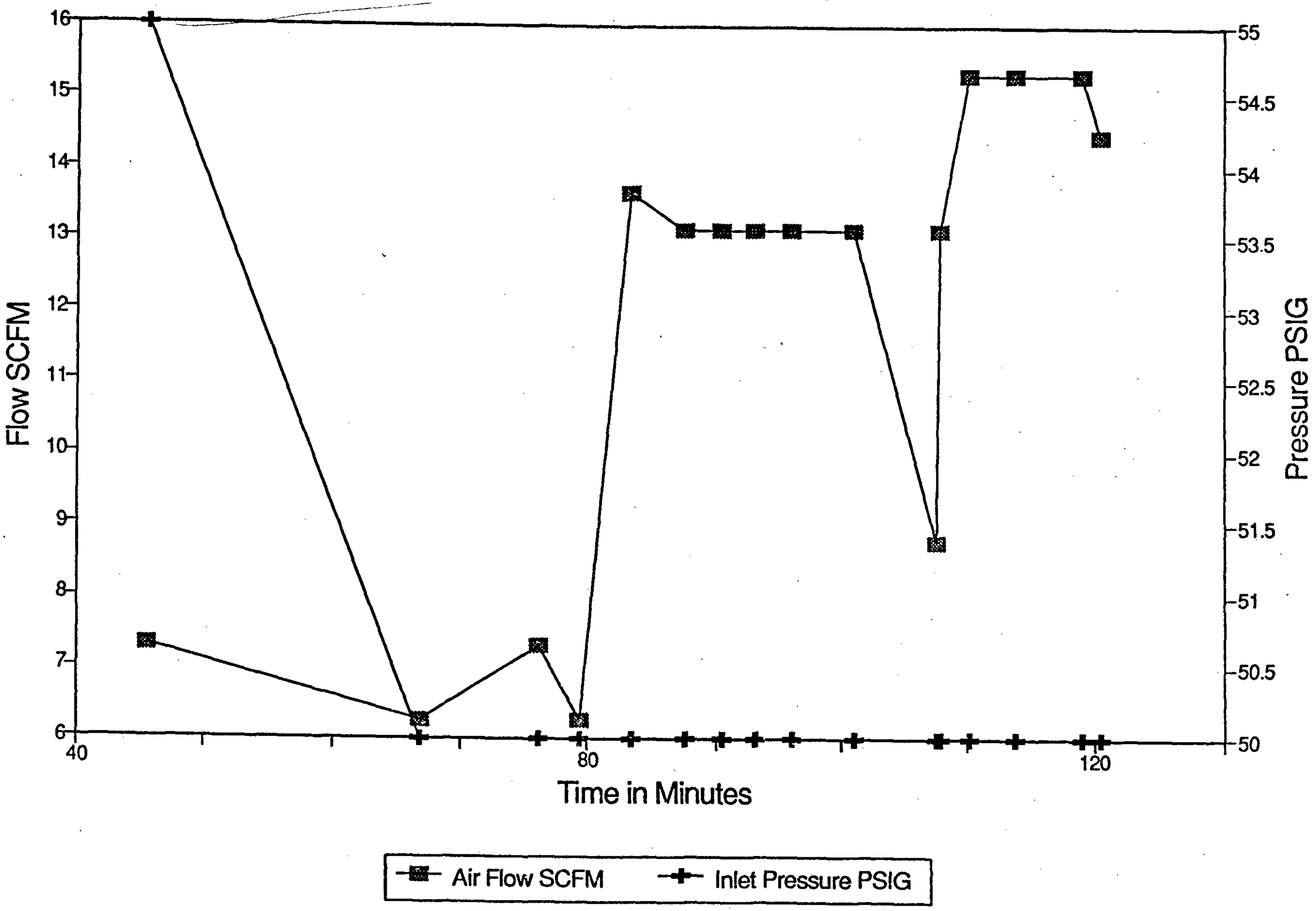

Cooling History
O2 Test #2
Temperature in K
Time in Minutes
300
250
200
150
100
50
0
100
200
300
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9


Mask Flow
O2 Test #2
100
95
90
85
80
75
70
65
O2 Concentration
60
50
40
30
20
10
0
Mask Flow LPM
0.00
2.00
4.00
6.00
Liters Liquid Withdrawn
O2 conc
Withdraw LPM

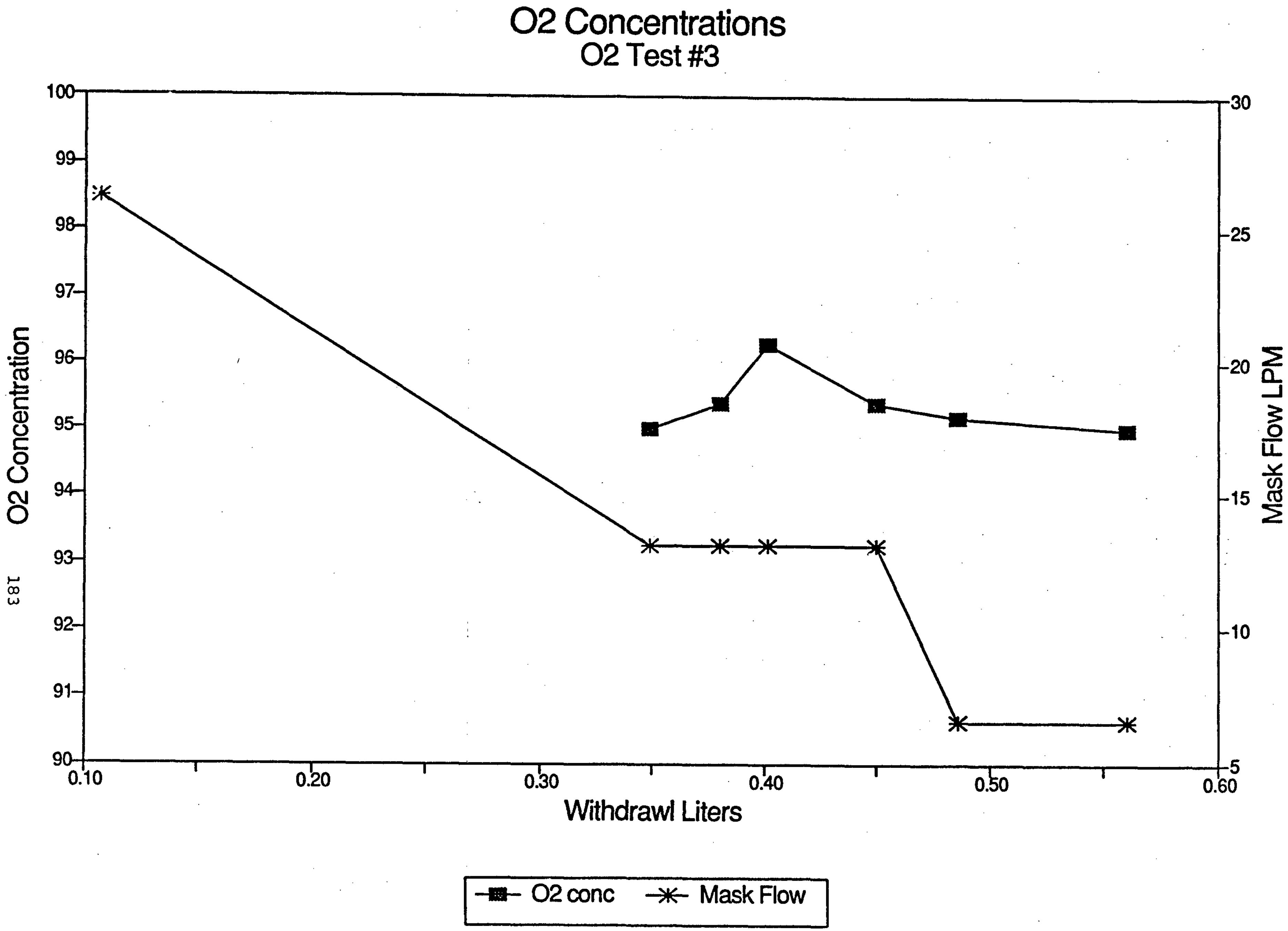


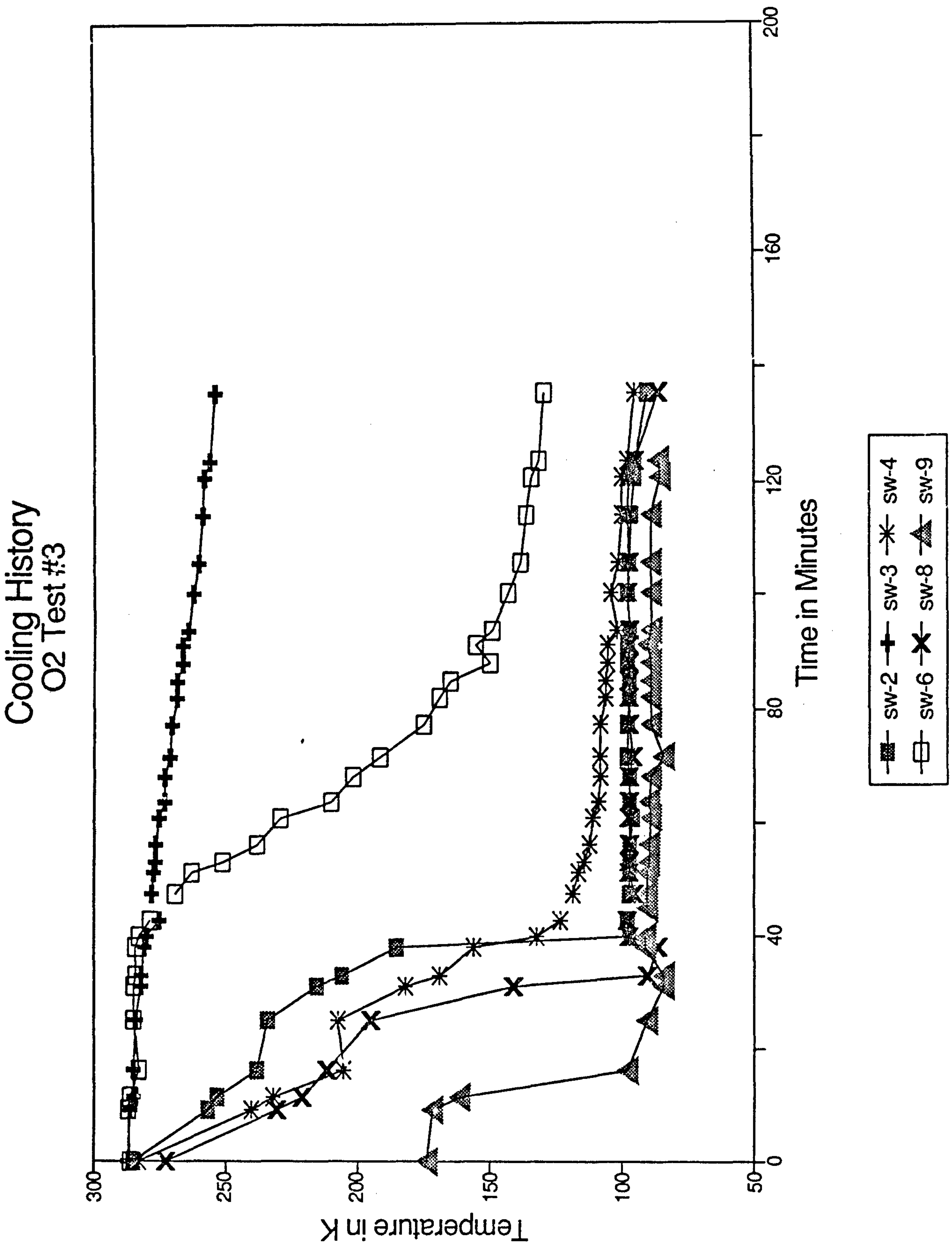
Dewar Filling-Oxygen
O2 Test #2
Liters Liquid
0
0.5
1
1.5
2
2.5
3
0
100
200
300
Time Minutes
Dewar 1-flow
Dewar 2-flow
Magnehelic Dewar 1
Magnehelic Dewar 2

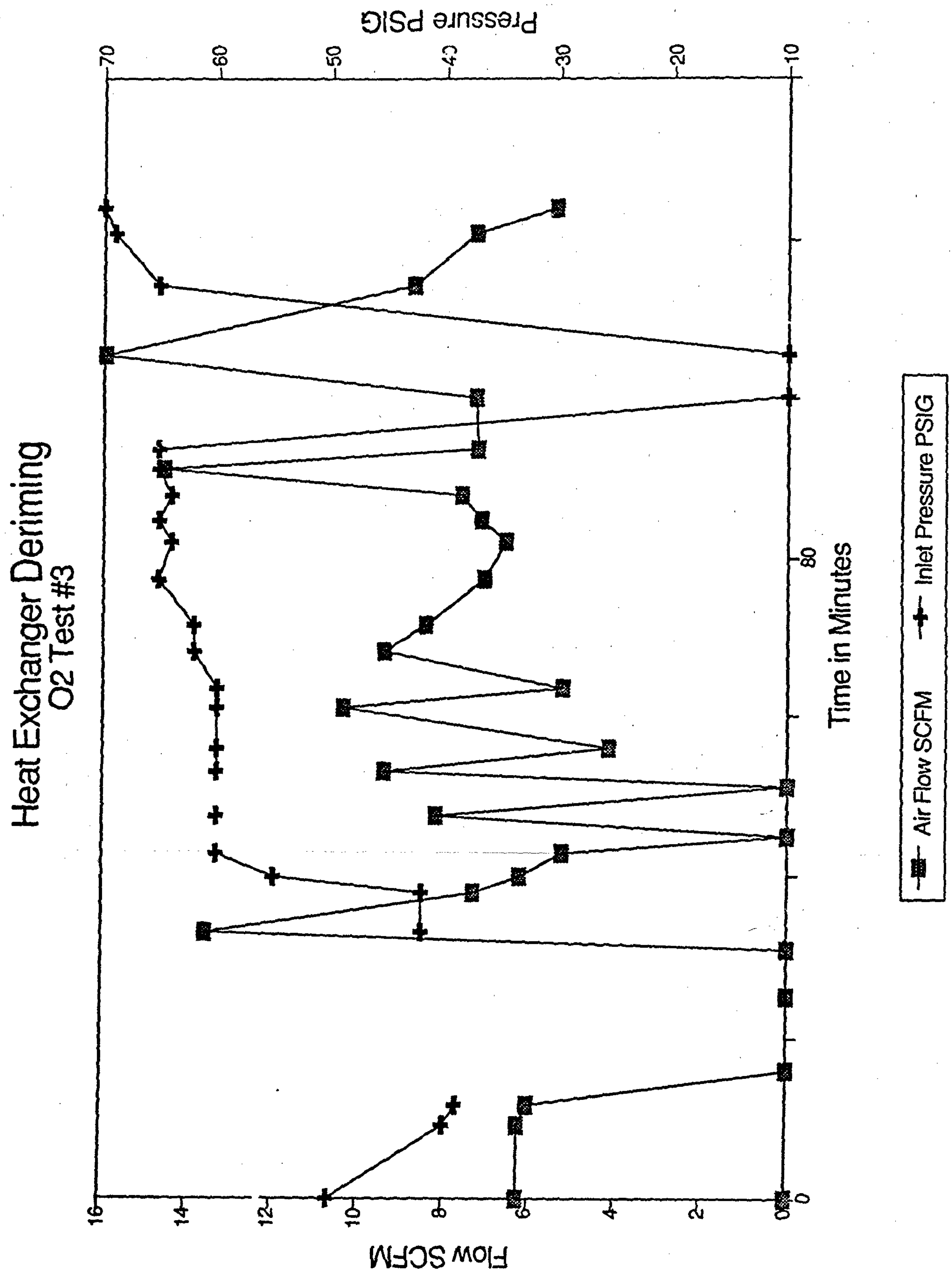
Heat Exchanger Deriming
O2 Test #2



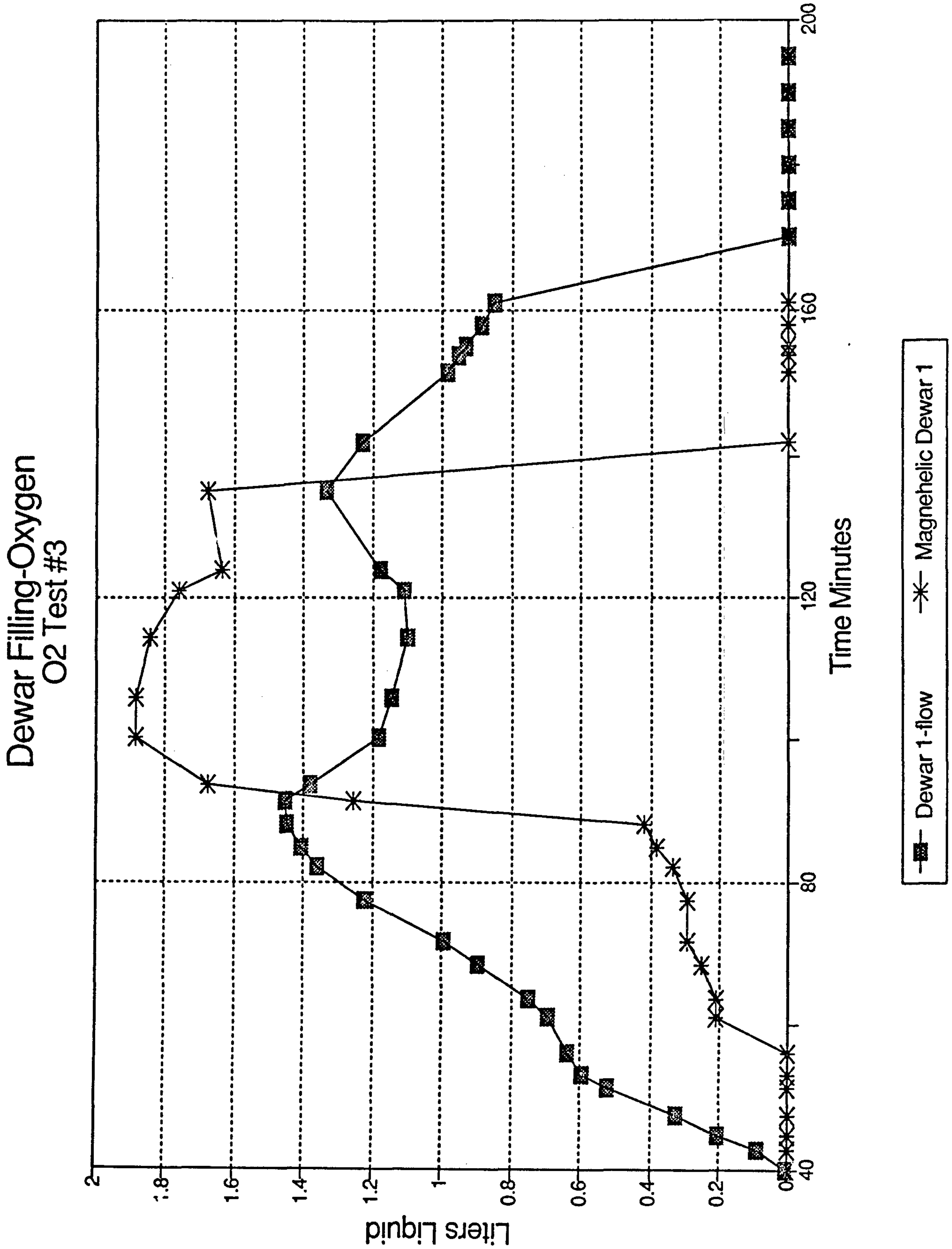
02 Test No. 3 Graphs


O2 Concentrations
O2 Test #3
O2 Concentration
100
99
98
97
96
95
94
93
92
91
90
Mask Flow LPM
30
25
20
15
10
5
0.10
0.20
0.30
0.40
0.50
0.60
Withdrawl Liters
O2 conc
Mask Flow

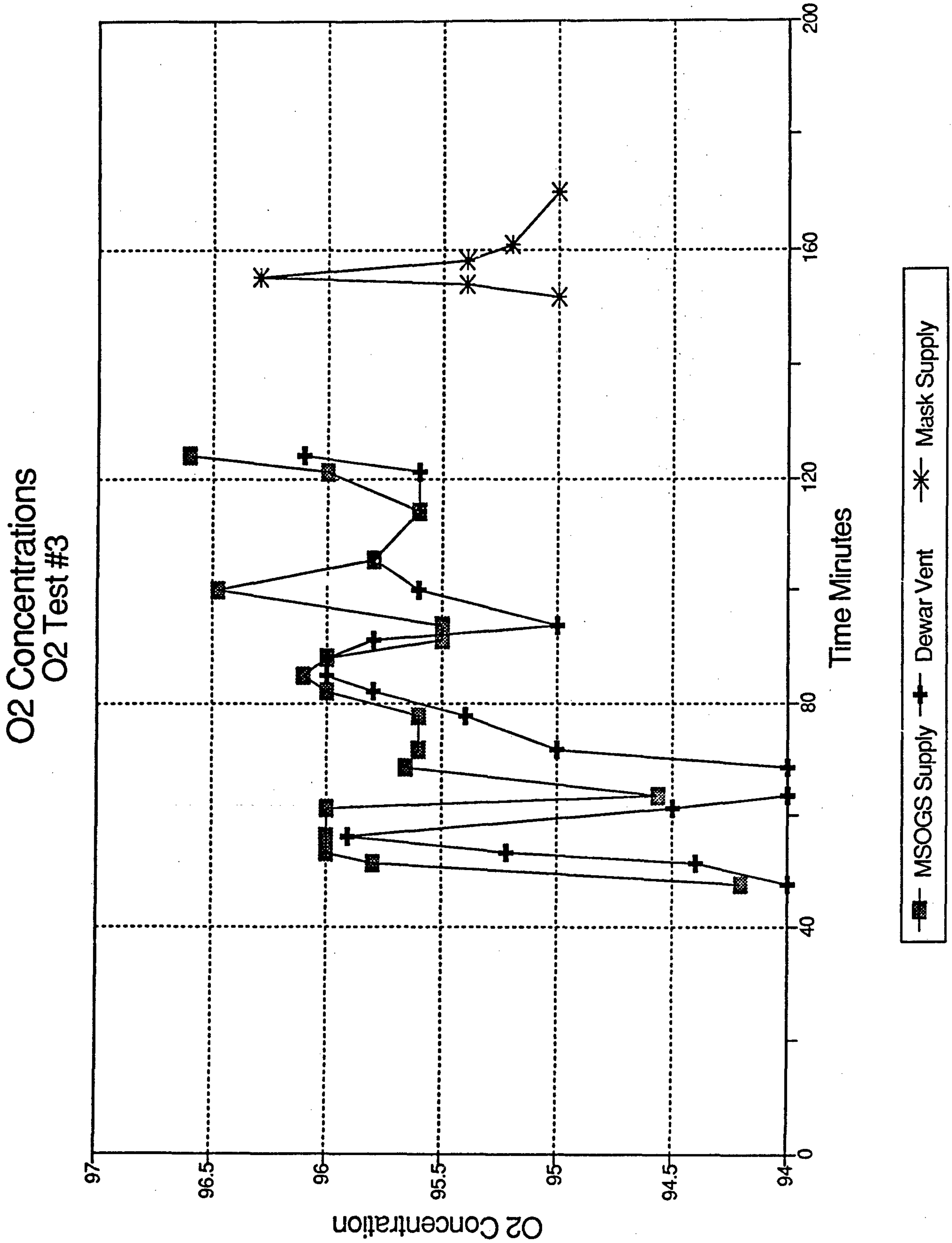

Cooling History
O2 Test #3
Temperature in K
300
250
200
150
100
50
0
40
80
120
160
200
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9



Heat Exchanger Deriming
O2 Test #3
Pressure PSIG
70
60
50
40
30
20
10
Flow SCFM
16
14
12
10
8
6
4
2
0
0
80
Time in Minutes
Air Flow SCFM
Inlet Pressure PSIG



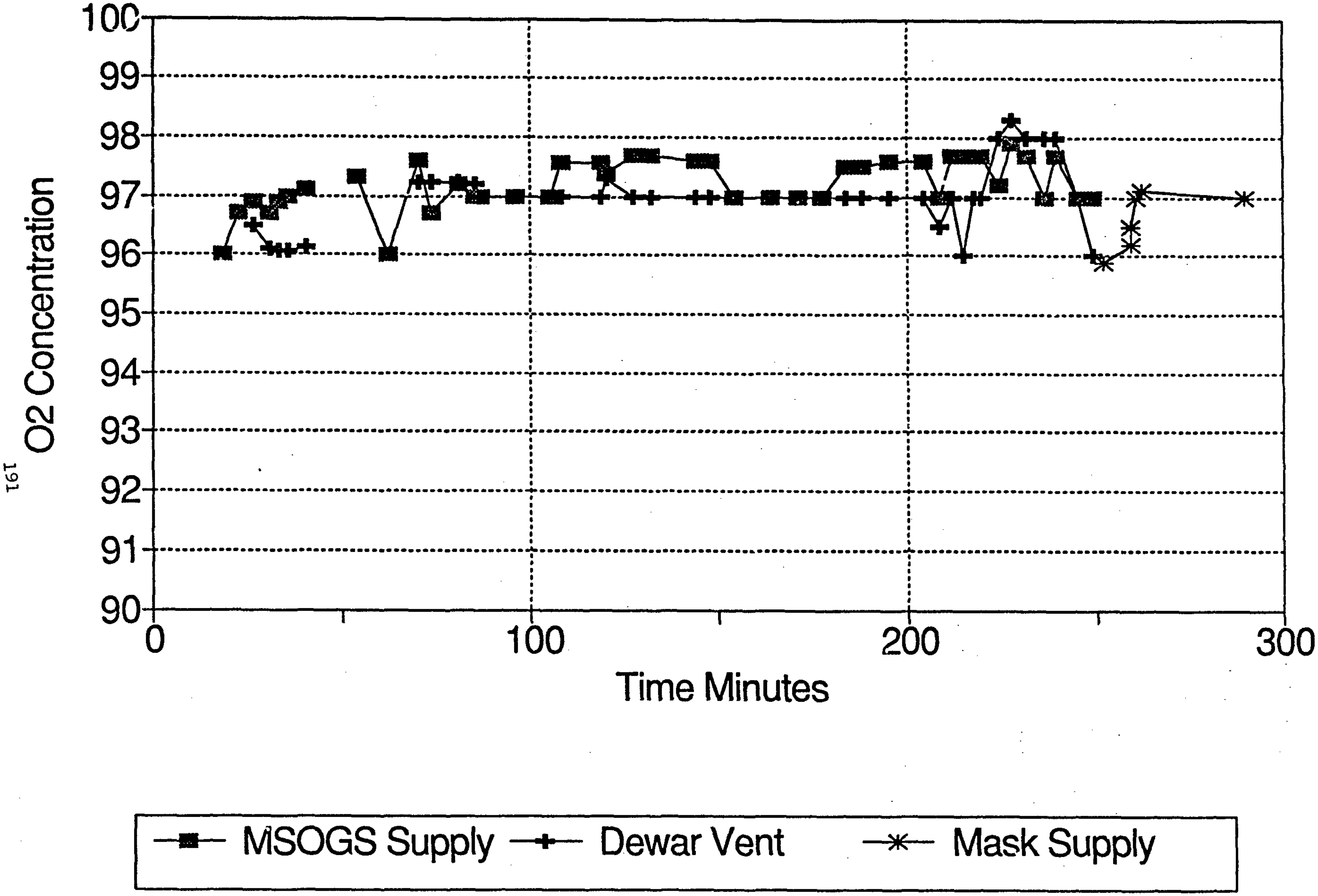
Dewar Filling-Oxygen
O2 Test #3
Liters Liquid
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time Minutes
40
80
120
160
200
Dewar 1-flow
Magnehelic Dewar 1

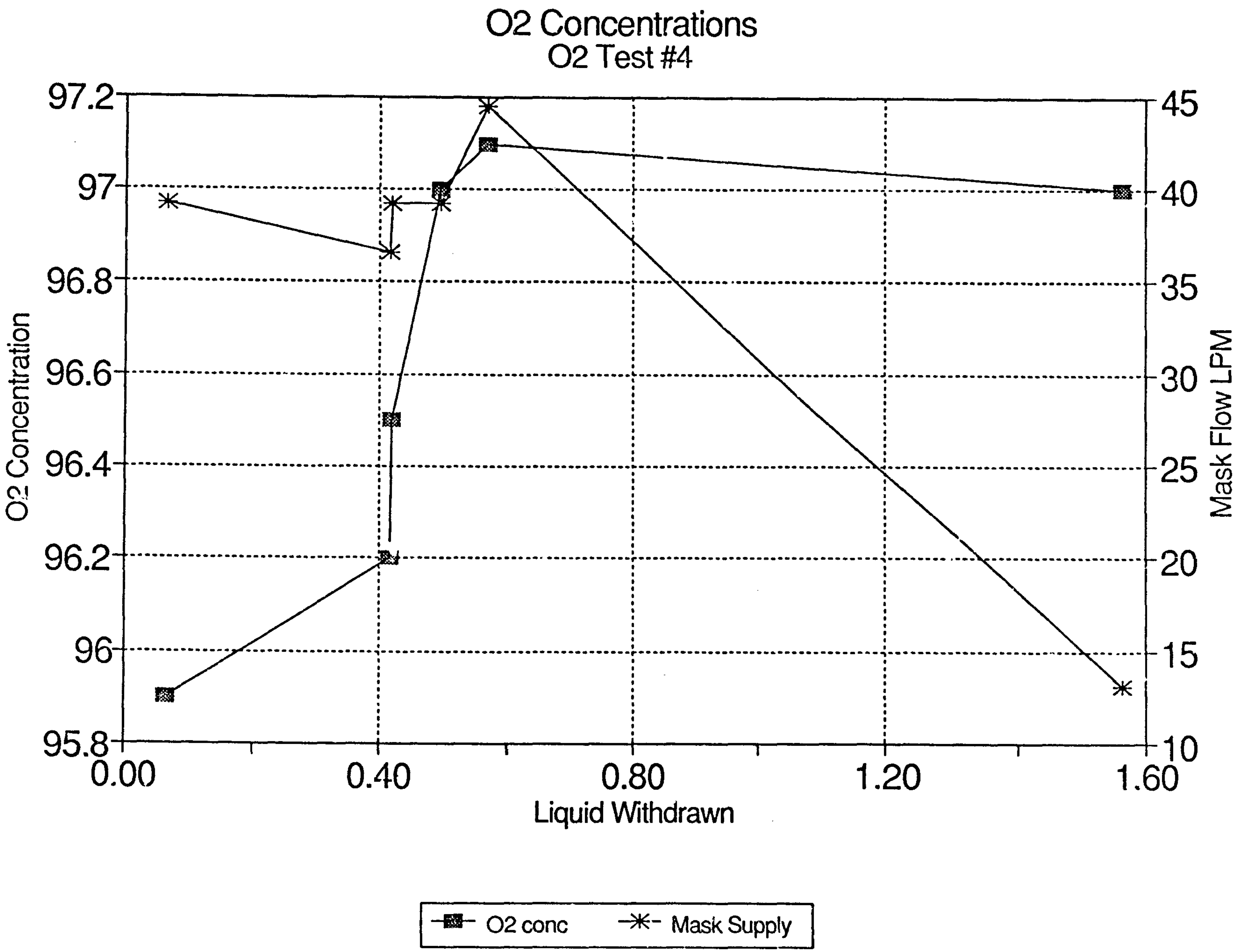


O2 Concentrations
O2 Test #3
O2 Concentration
97
96.5
96
95.5
95
94.5
94
0
40
80
120
160
200
Time Minutes
MSOGS Supply
Dewar Vent
Mask Supply

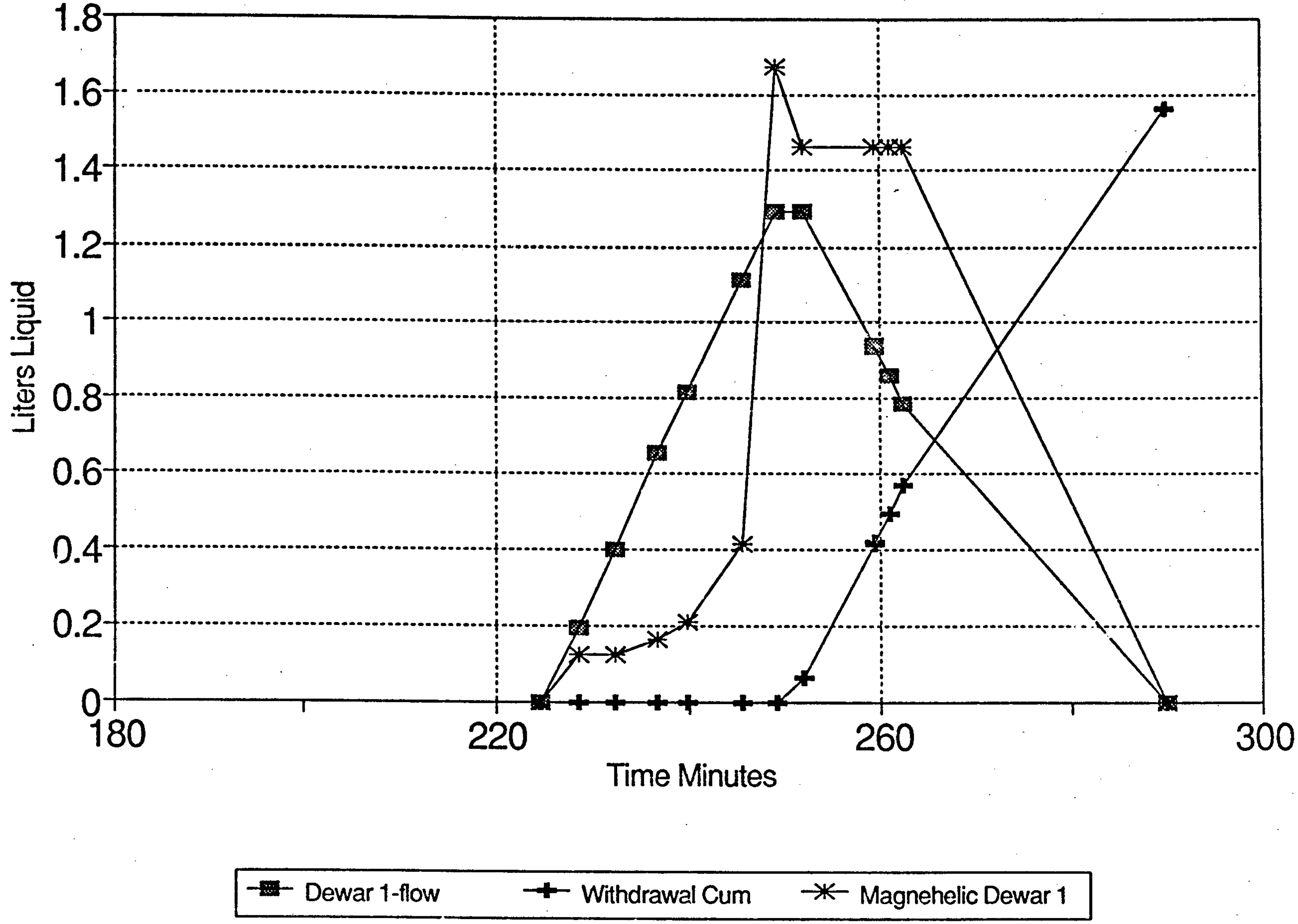
02 Test No. 4 Graphs

O2 Concentrations
O2 Test # 4

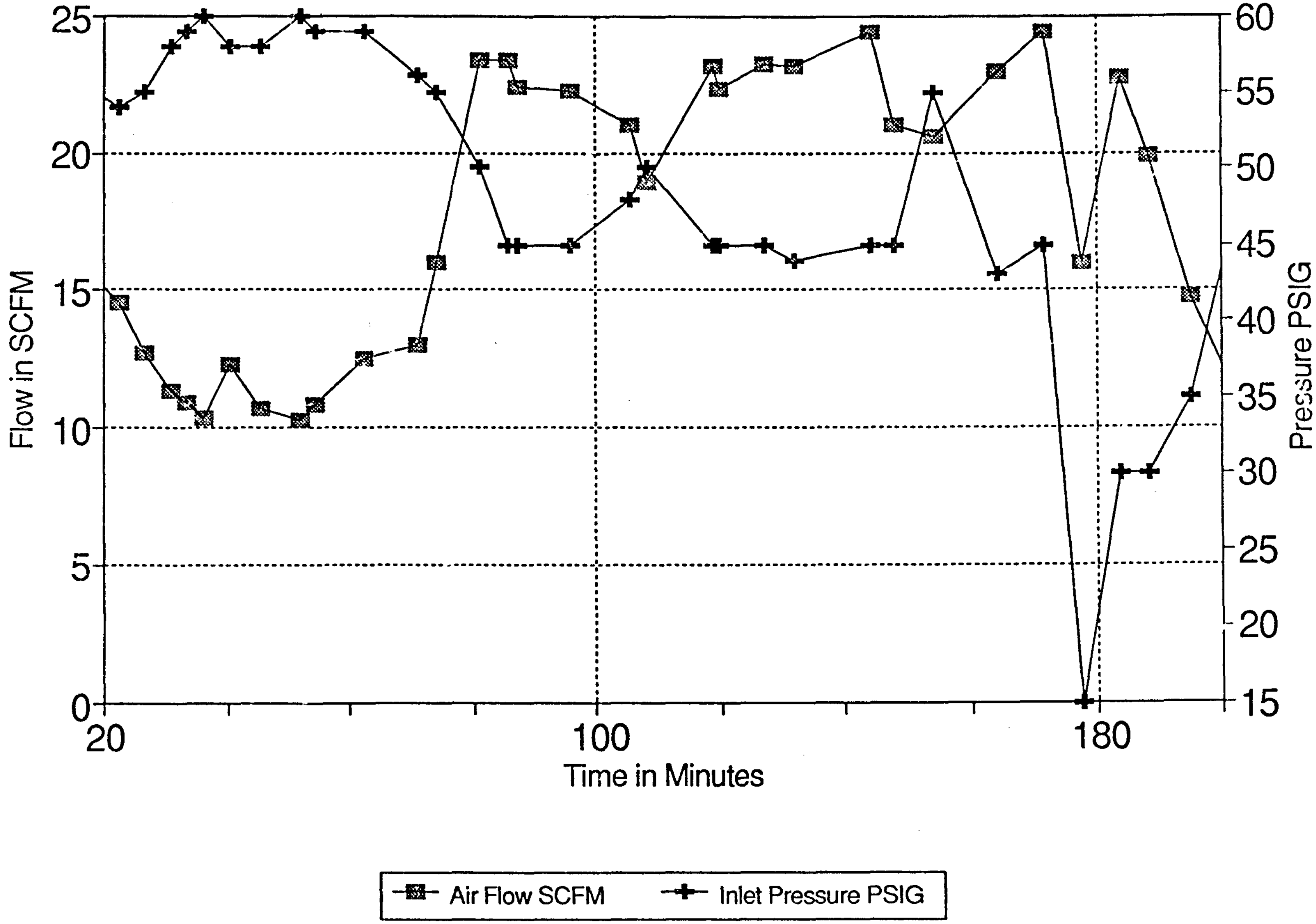


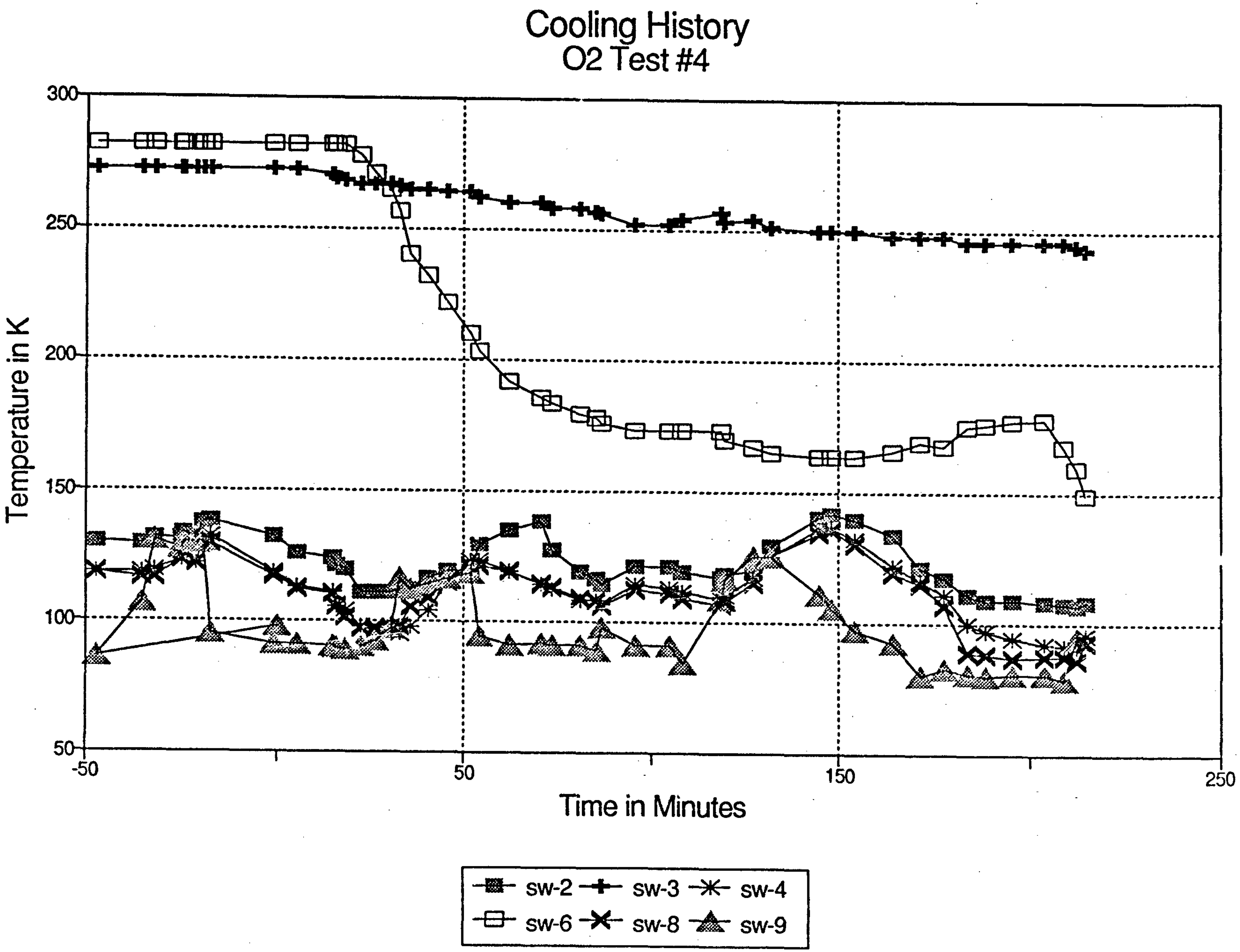

O2 Concentrations
O2 Test #4
O2 Concentration
Mask Flow LPM
Liquid Withdrawn
97.2
97
96.8
96.6
96.4
96.2
96
95.8
45
40
35
30
25
20
15
10
0.00
0.40
0.80
1.20
1.60
O2 conc
Mask Supply

Dewar Filling-Oxygen
O2 Test #4

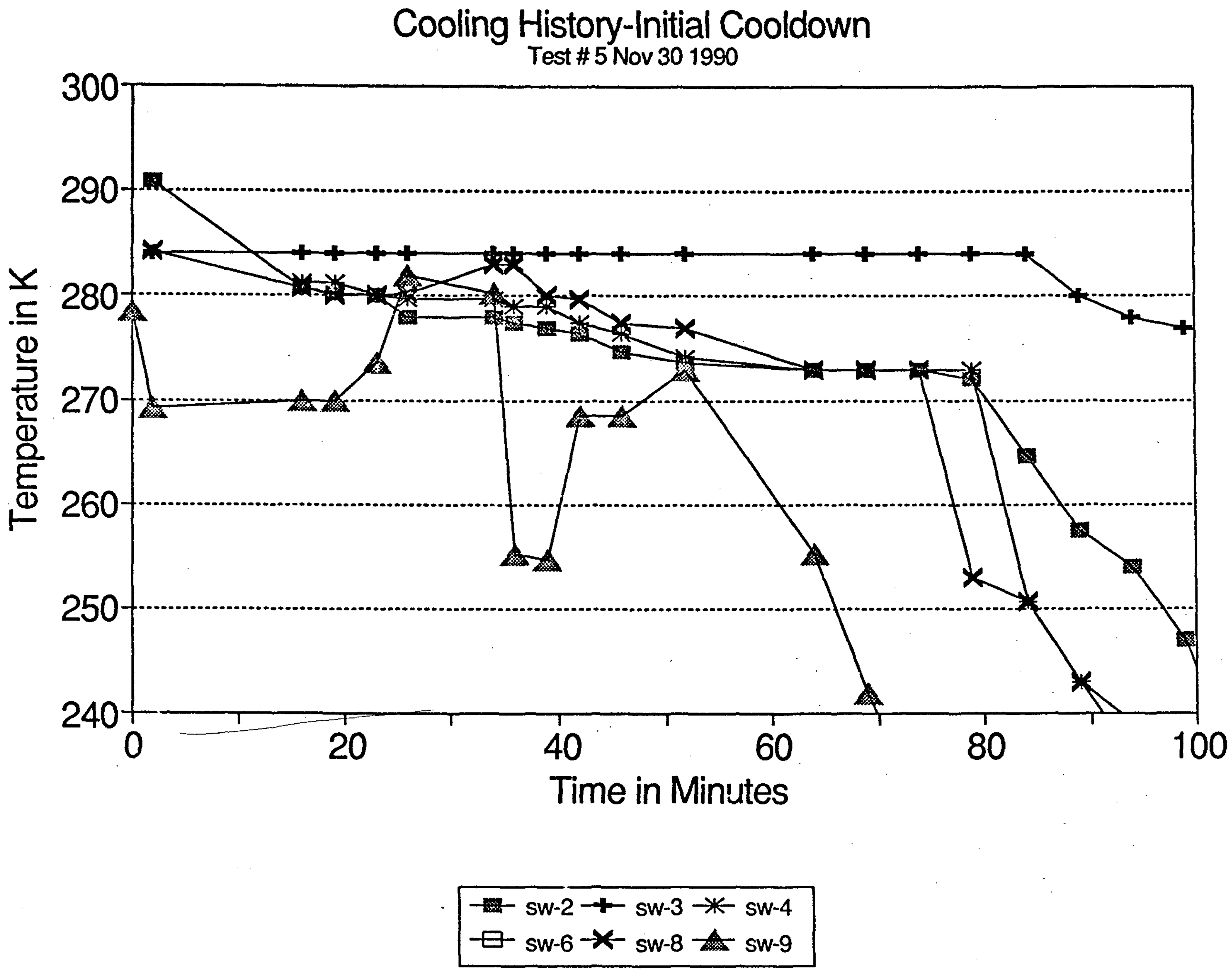


Heat Exchanger Deriming
O2 Test # 4



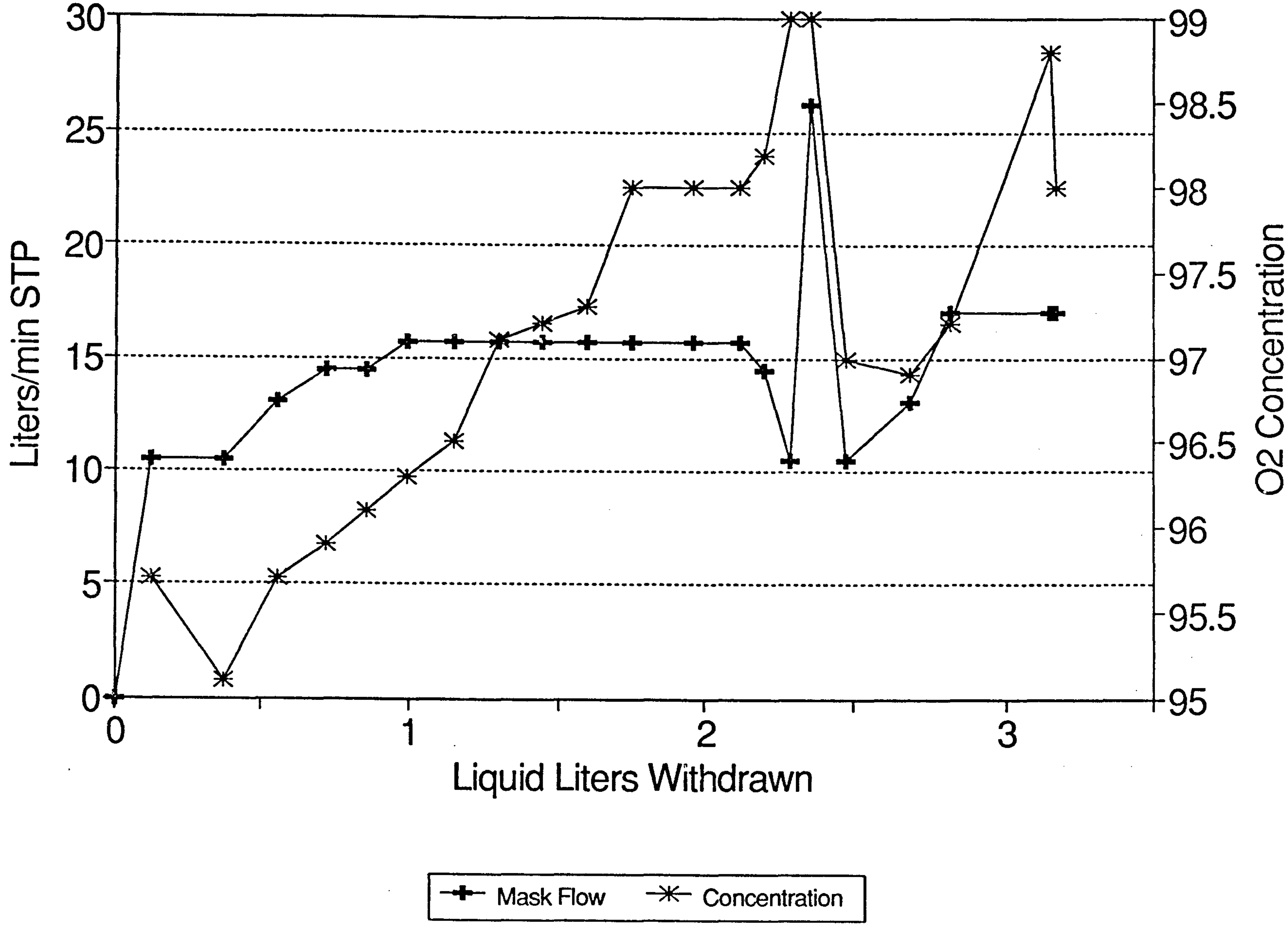

Cooling History
O2 Test #4
Temperature in K
300
250
200
150
100
50
-50
50
150
250
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9

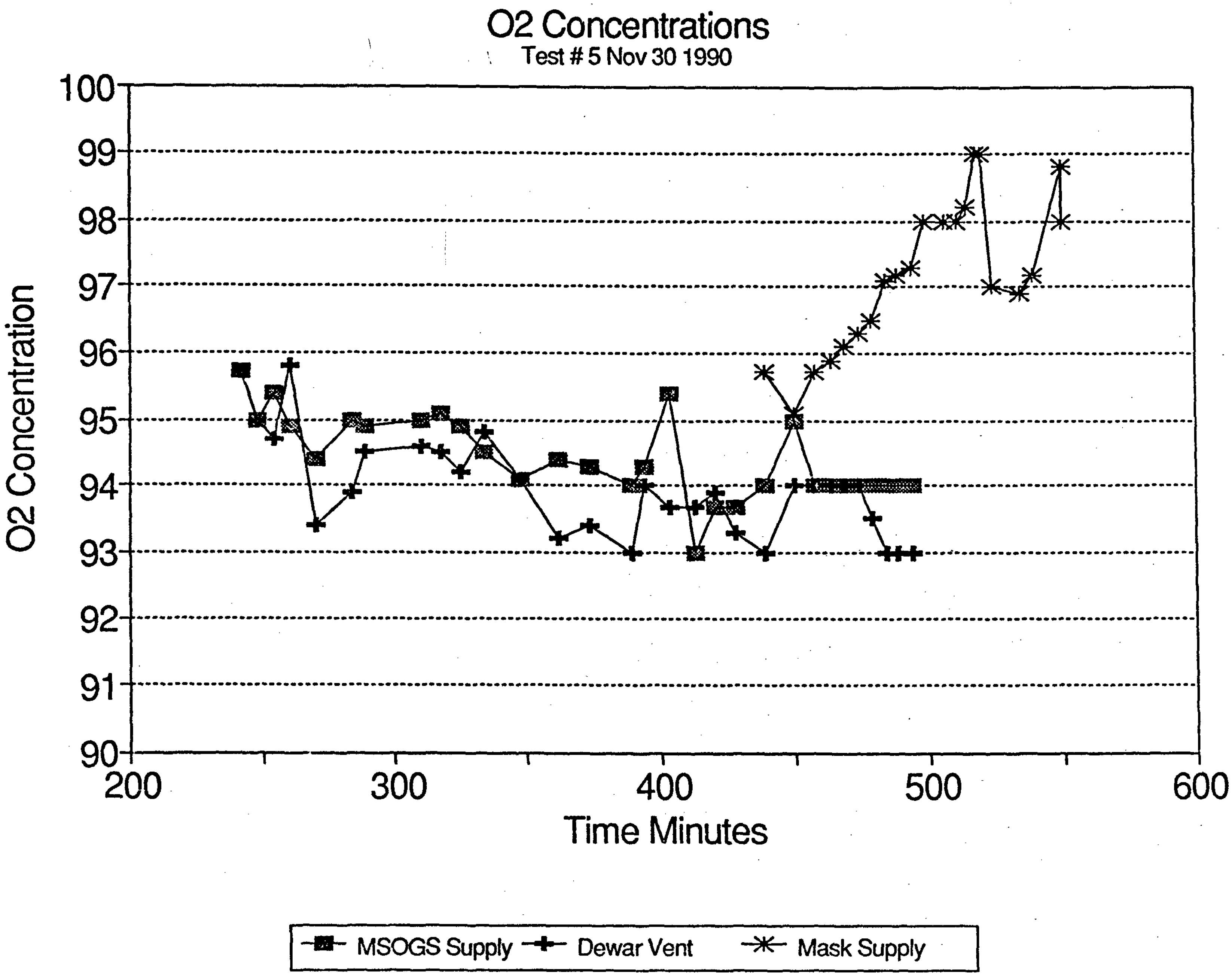
02 Test No. 5 Graphs

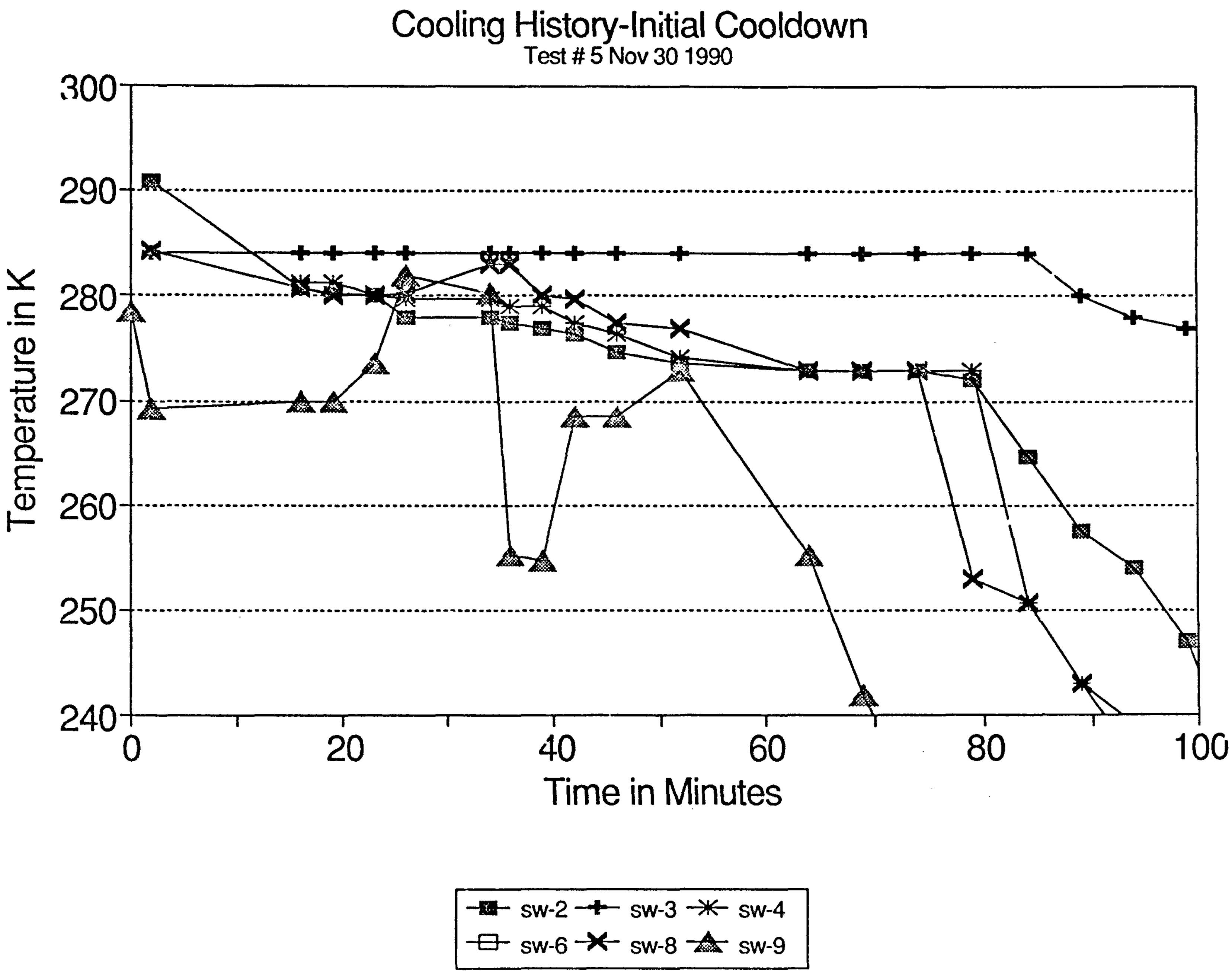


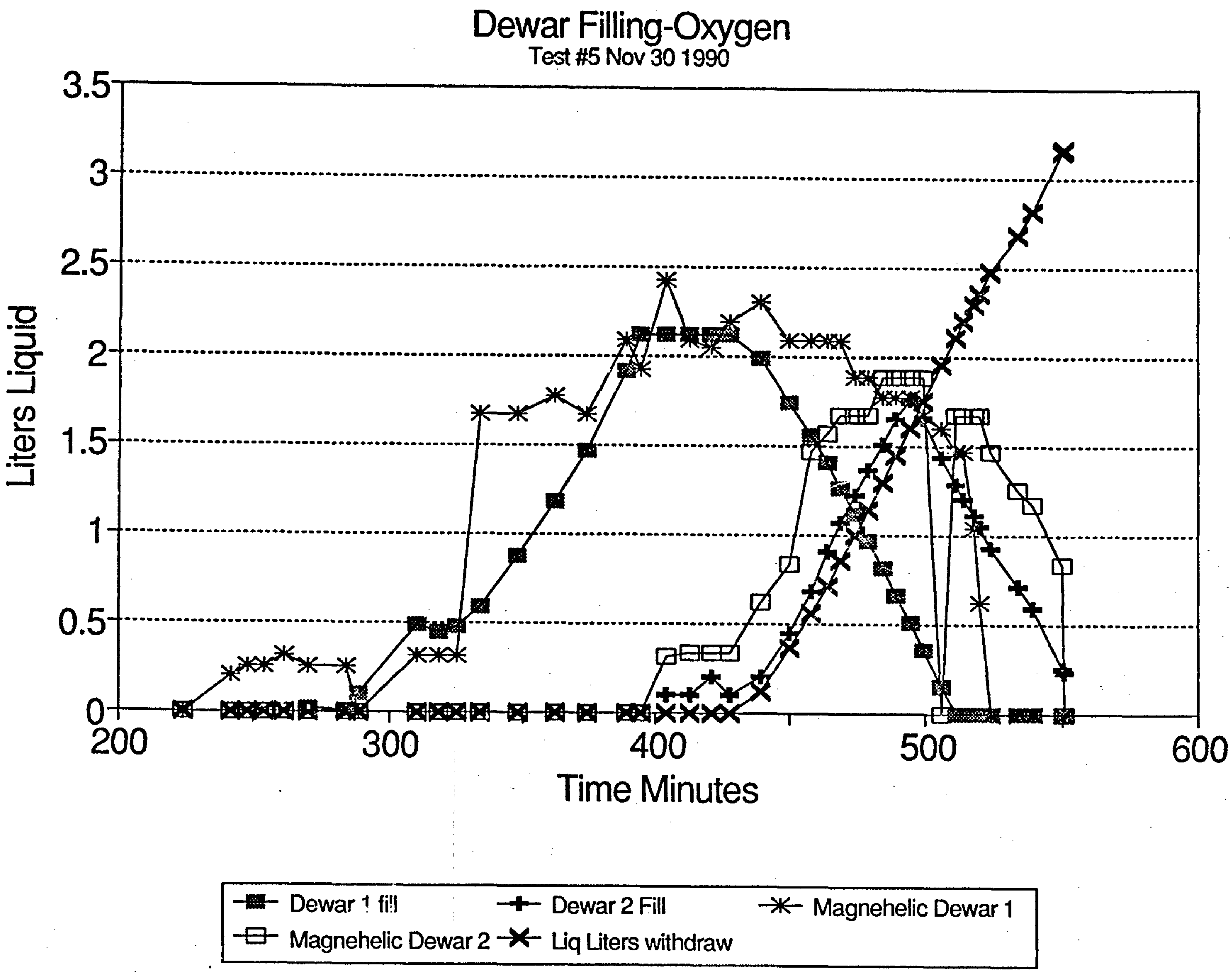
Cooling History-Initial Cooldown
Test # 5 Nov 30 1990
Temperature in K
300
290
280
270
260
250
240
0
20
40
60
80
100
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9

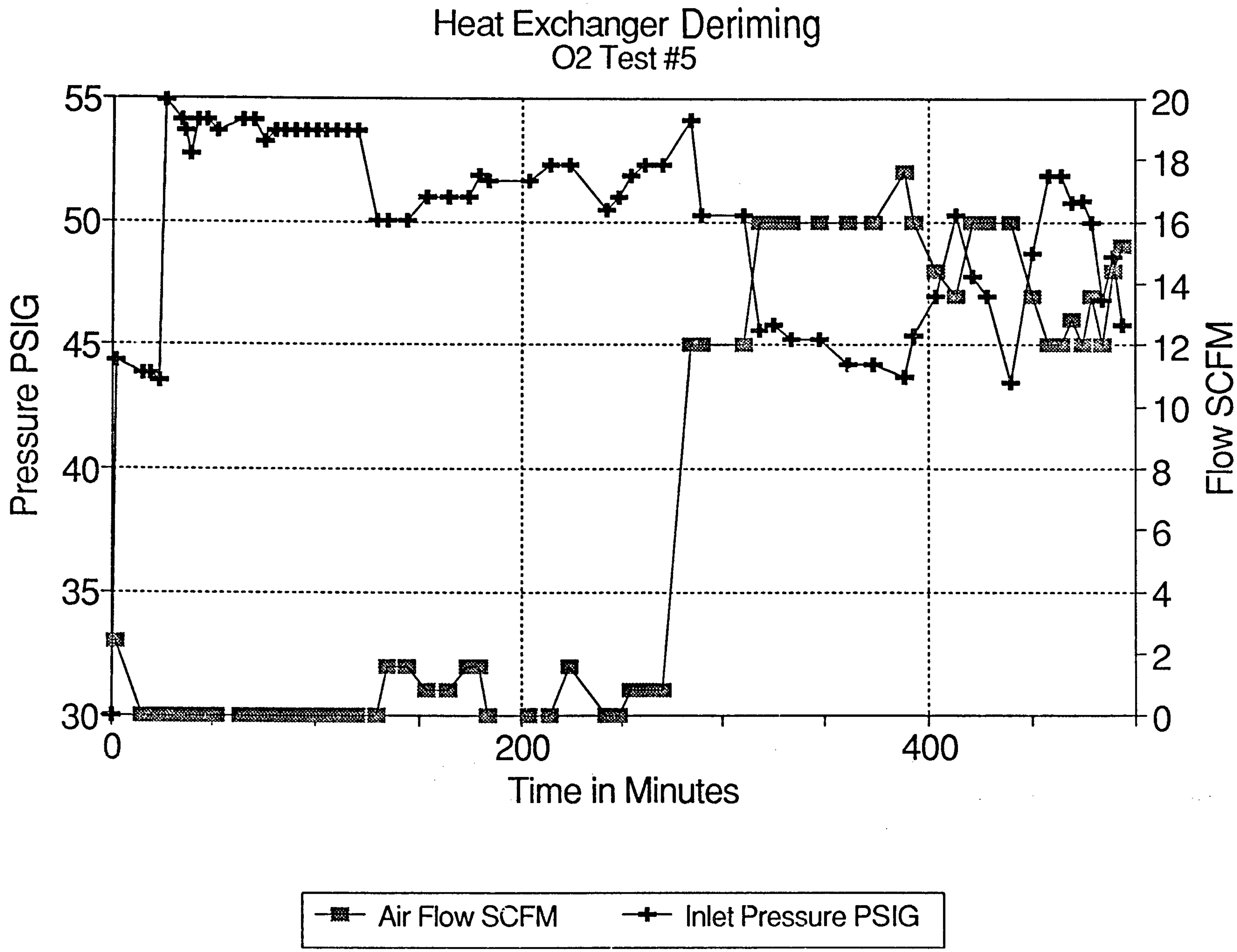
O2 Concentrations
Test # 5 Nov 30 1990

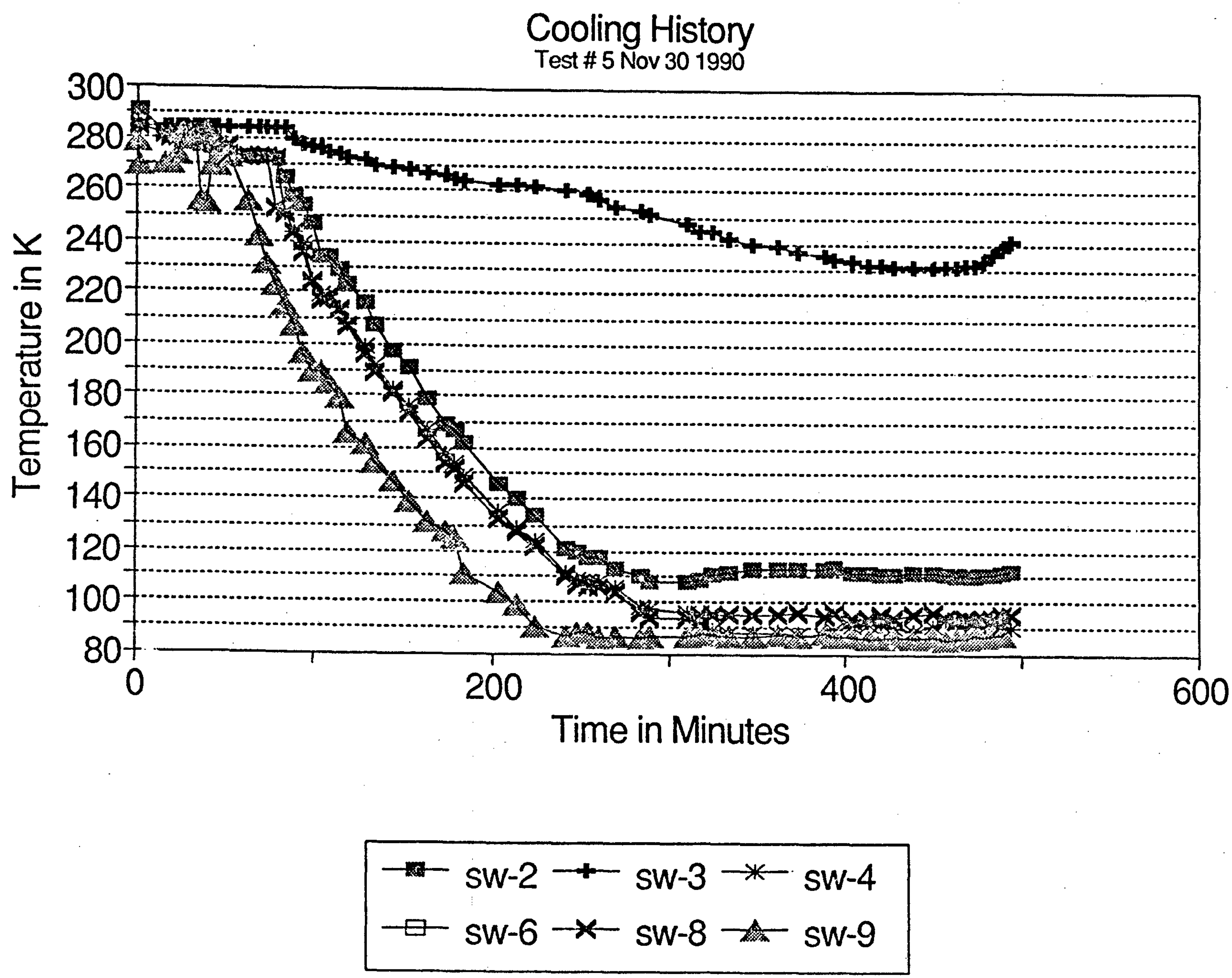



O2 Concentrations
Test # 5 Nov 30 1990
O2 Concentration
100
99
98
97
96
95
94
93
92
91
90
200
300
400
500
600
Time Minutes
MSOGS Supply
Dewar Vent
Mask Supply

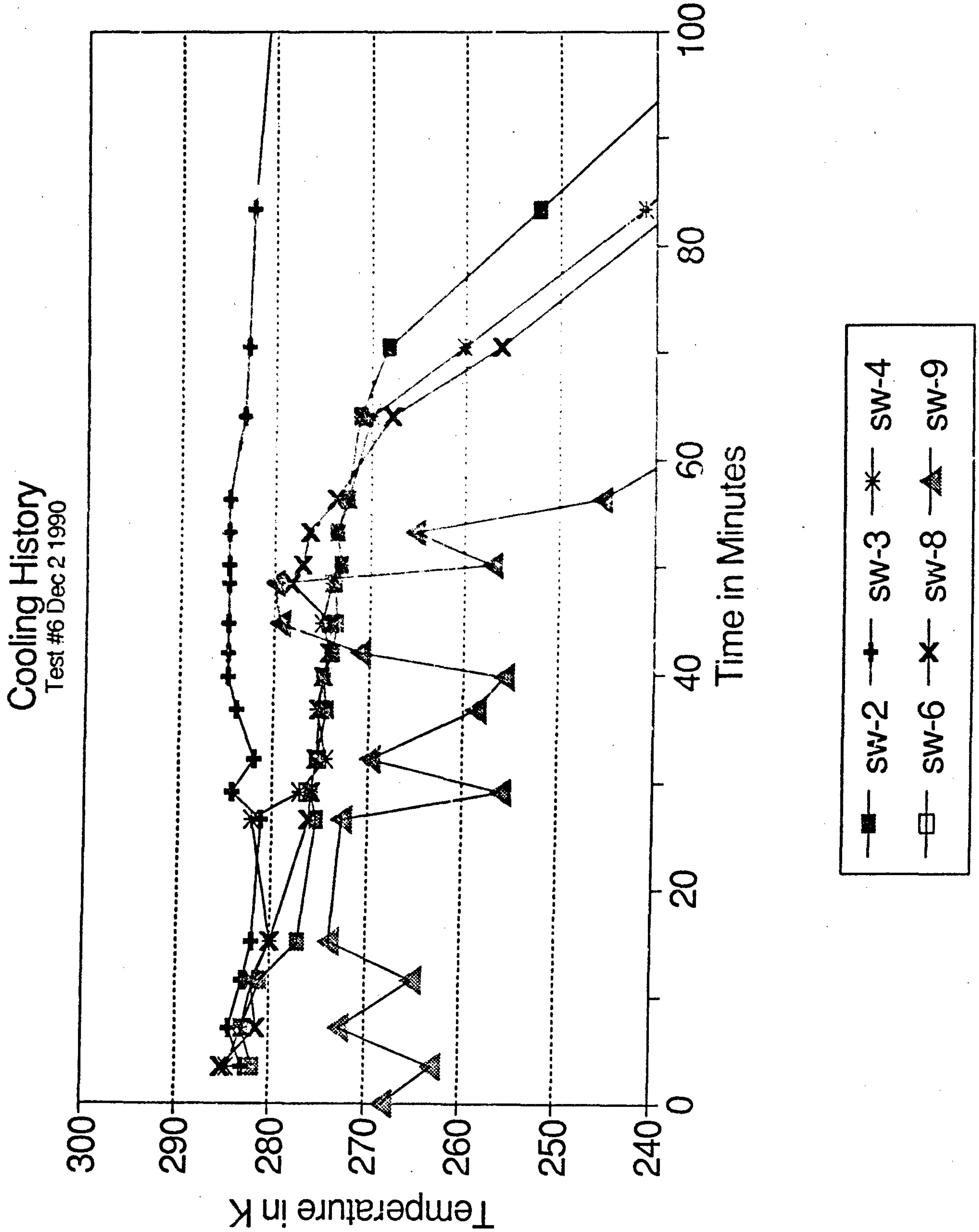

Cooling History-Initial Cooldown
Test # 5 Nov 30 1990
Temperature in K
300
290
280
270
260
250
240
0
20
40
60
80
100
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9

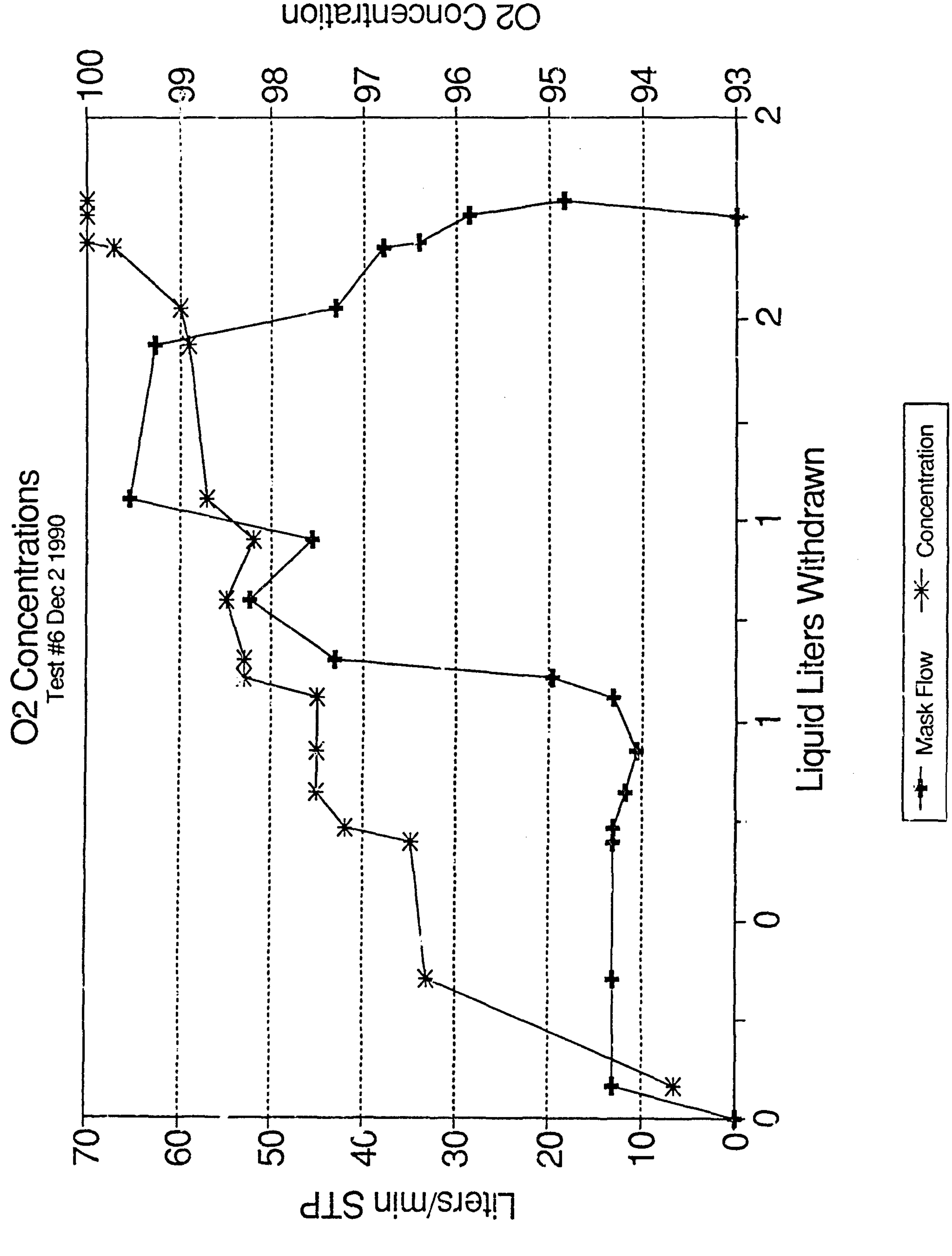

Dewar Filling-Oxygen
Test #5 Nov 30 1990
Liters Liquid
3.5
3
2.5
2
1.5
1
0.5
0
200
300
400
500
600
Time Minutes
Dewar 1 fill
Dewar 2 Fill
Magnehelic Dewar 1
Magnehelic Dewar 2
Liq Liters withdraw


Heat Exchanger Deriming
O2 Test #5
Pressure PSIG
55
50
45
40
35
30
0
200
400
Time in Minutes
Flow SCFM
20
18
16
14
12
10
8
6
4
2
0
Air Flow SCFM
Inlet Pressure PSIG

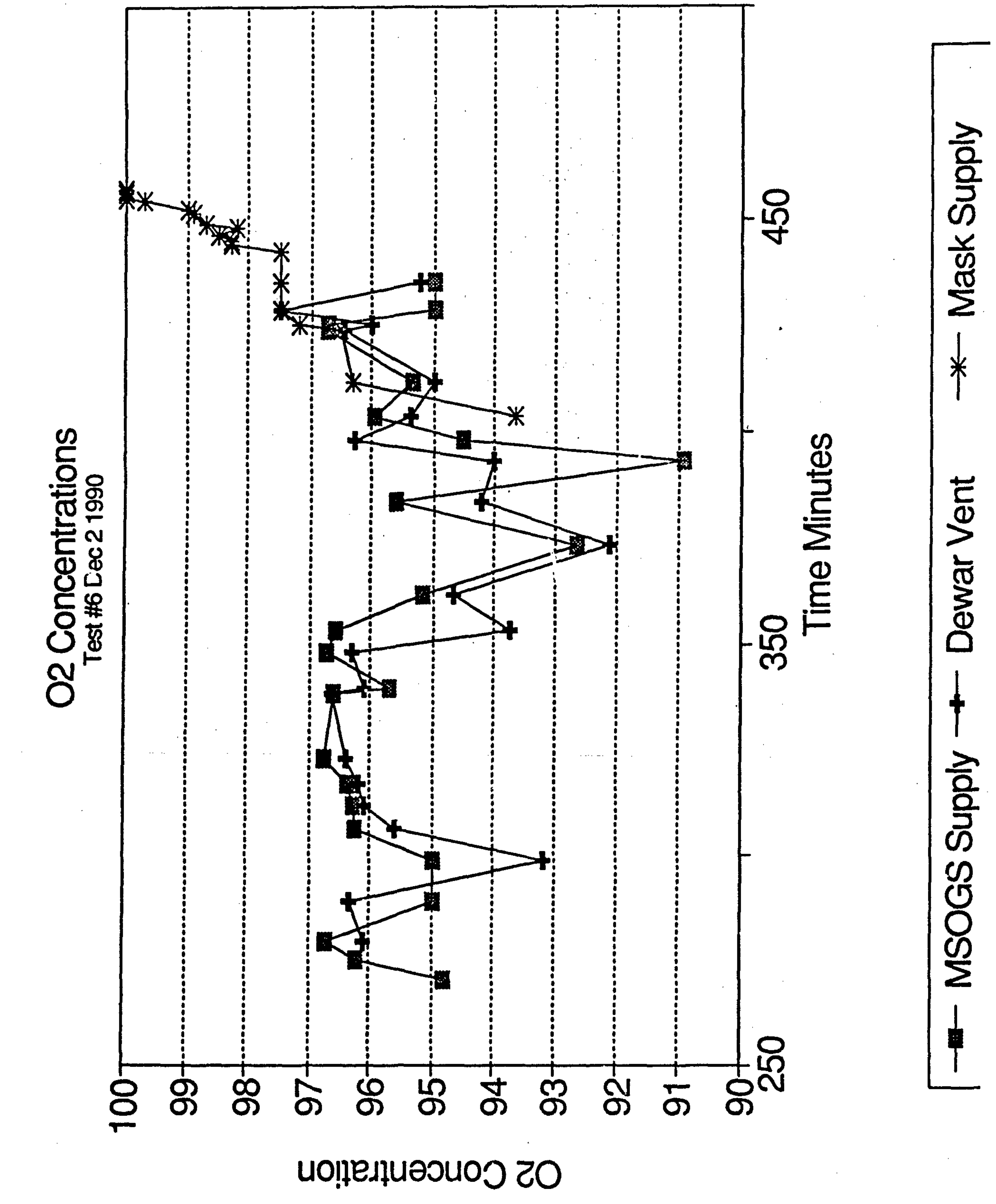

Cooling History
Test # 5 Nov 30 1990
Temperature in K
300
280
260
240
220
200
180
160
140
120
100
80
0
200
400
600
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9

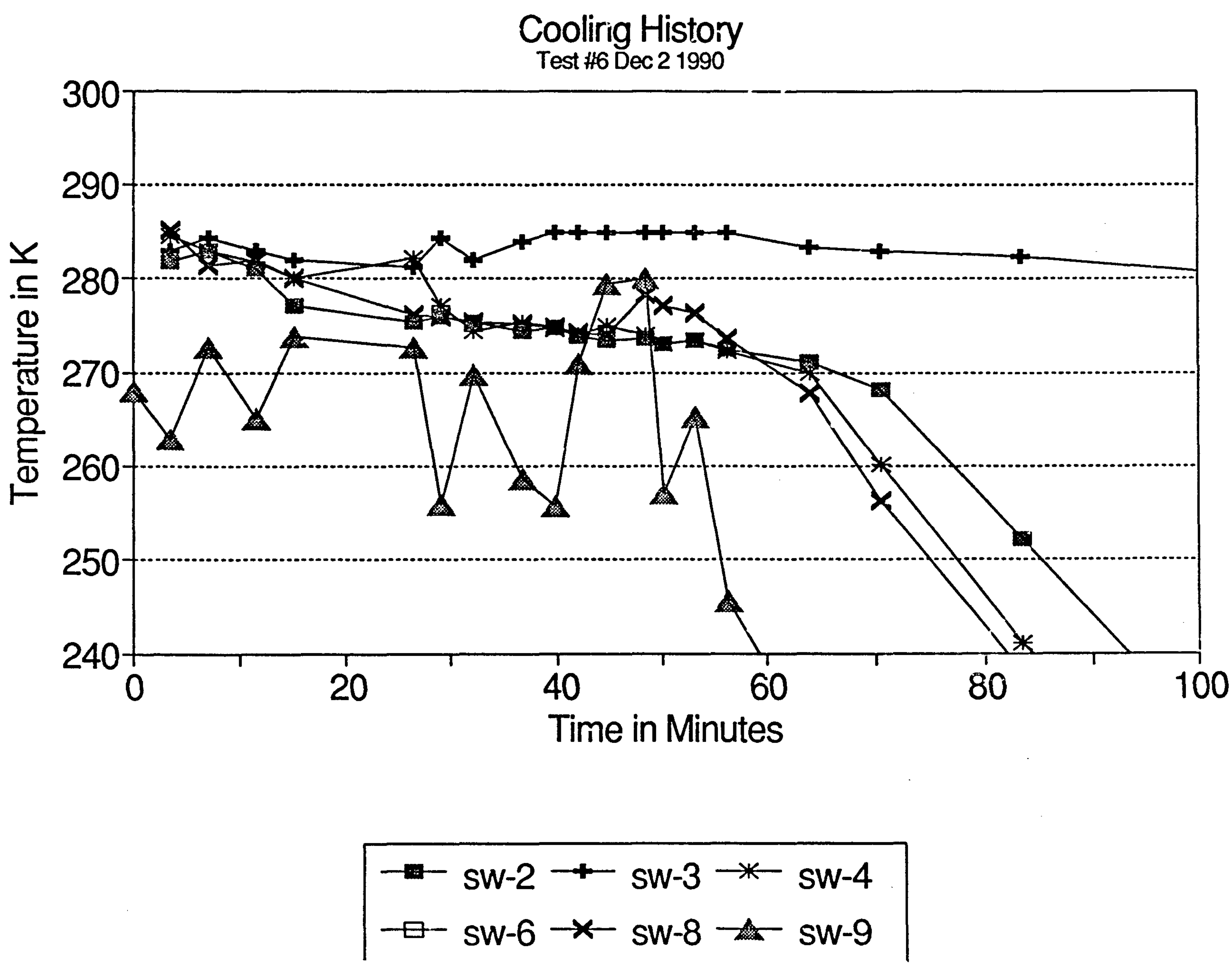
02 Test No. 6 Graphs

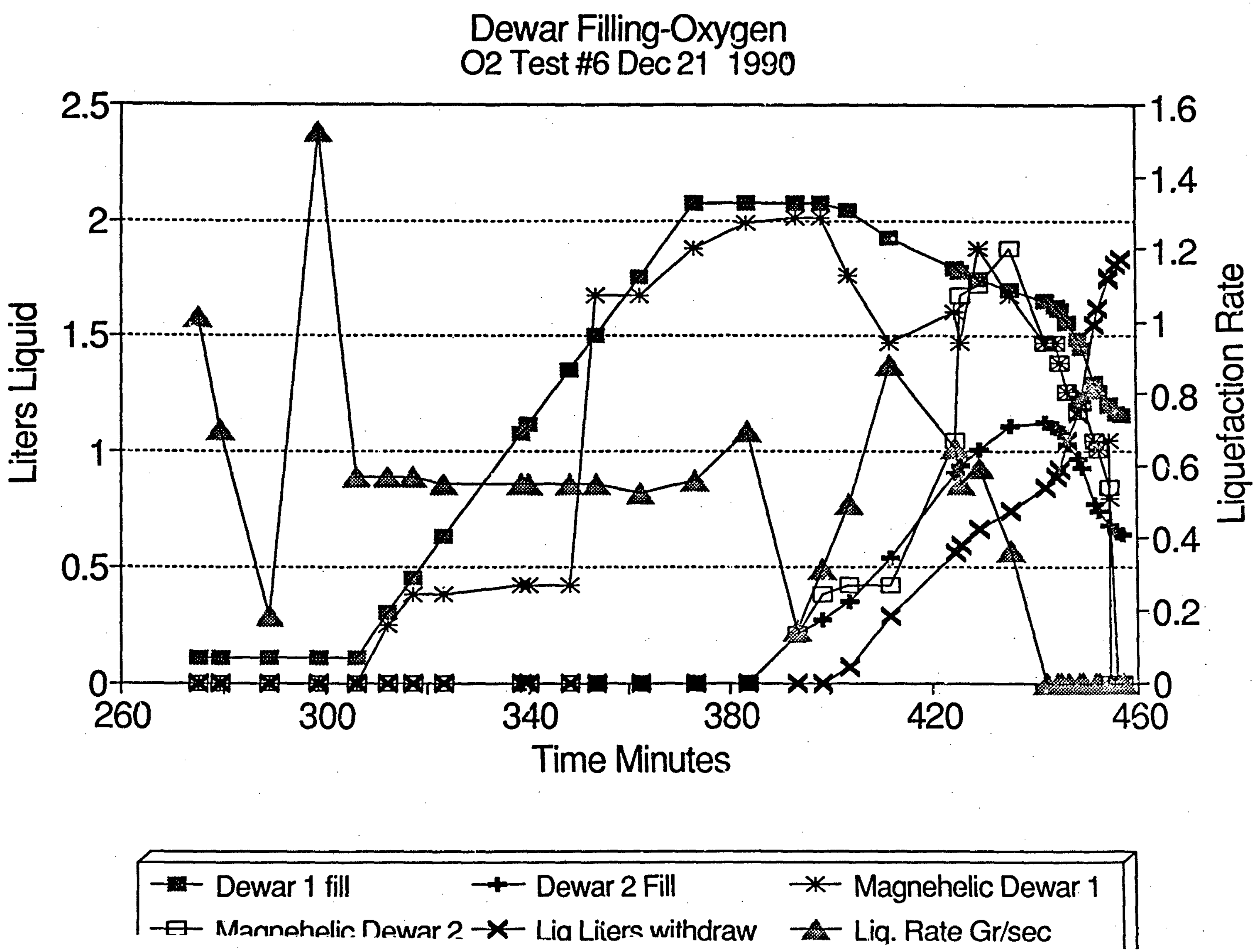

Cooling History
Test #6 Dec 2 1990
Temperature in K
300
290
280
270
260
250
240
0
20
40
60
80
100
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9

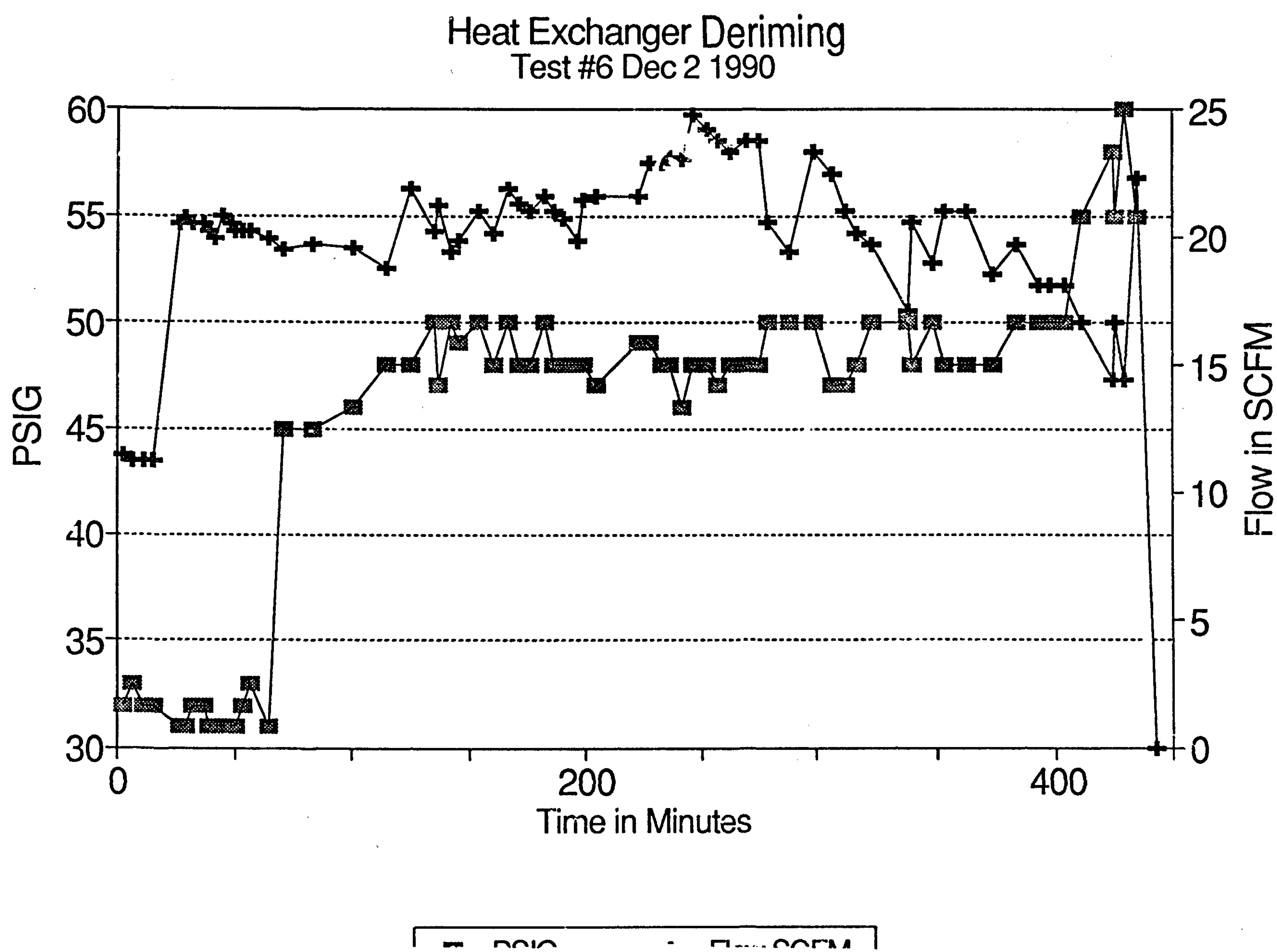


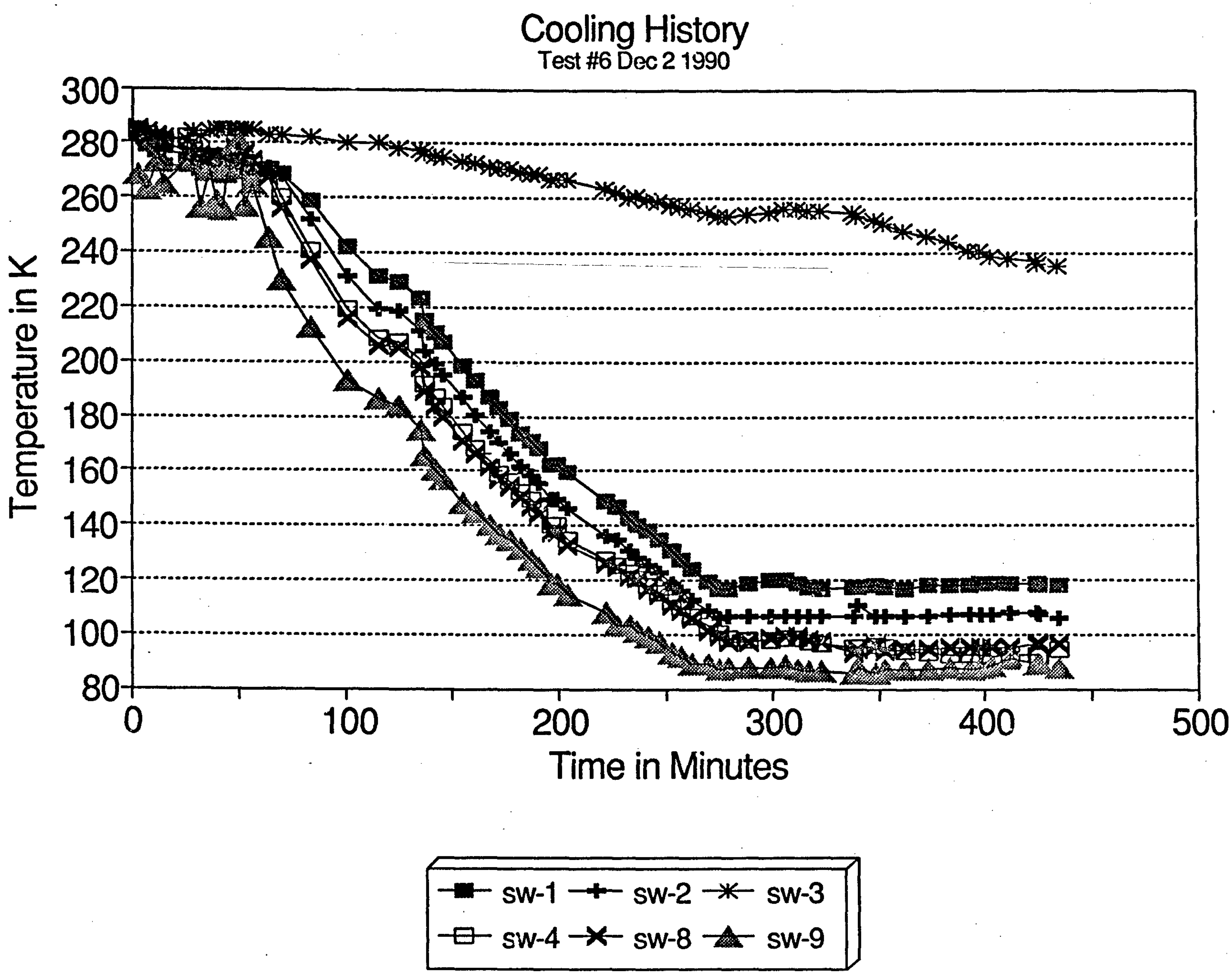
O2 Concentrations
Test #6 Dec 2 1990
Liters/min STP
O2 Concentration
Liquid Liters Withdrawn
Mask Flow
Concentration
70
60
50
40
30
20
10
0
100
99
98
97
96
95
94
93
0
1
2


O2 Concentrations
Test #6 Dec 2 1990
O2 Concentration
100
99
98
97
96
95
94
93
92
91
90
250
350
450
Time Minutes
MSOGS Supply
Dewar Vent
Mask Supply


Cooling History
Test #6 Dec 2 1990
Temperature in K
300
290
280
270
260
250
240
0
20
40
60
80
100
Time in Minutes
sw-2
sw-3
sw-4
sw-6
sw-8
sw-9


Dewar Filling-Oxygen
O2 Test #6 Dec 21 1990
Liters Liquid
Liquefaction Rate
Time Minutes
2.5
2
1.5
1
0.5
0
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
260
300
340
380
420
460
Dewar 1 fill
Dewar 2 Fill
Magnehelic Dewar 1
Lig. Rate Gr/sec


Heat Exchanger Deriming
Test #6 Dec 2 1990
PSIG
60
55
50
45
40
35
30
Flow in SCFM
25
20
15
10
5
0
Time in Minutes
0
200
400



Cooling History
Test #6 Dec 2 1990
Temperature in K
300
280
260
240
220
200
180
160
140
120
100
80
0
100
200
300
400
500
Time in Minutes
sw-1
sw-2
sw-3
sw-4
sw-8
sw-9

7.7 Nomenclature

Note on Abbreviations

The following abbreviations are used throughout the report:

mm Hg is millimeter of mercury - pressure
LPM is liter per minute oxygen flow
NTP is normal temperature (70°F) and pressure (14.7 psia)
ATP is ambient (in cabin) temperature and pressure

•U.S. GOVERNMENT PRINTING OFFICE 1993-0-761-052/60065

END

FILMED

DATE: 4-93

DTIC